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# THE ANALYSIS OF A LONGITUDINAL CONTROL SYSTEM FOR UNDERWATER VEHICLES

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A general longitudinal feedback control system containing pitch, pitch rate, depth, and depth rate feedback is described. The Laplace domain transfer functions for each feedback loop are developed. A computer analysis program utilizing the root locus technique is developed for aiding in the design of the control system. An illustrative example design problem is included.

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#### INTRODUCTION

The requirement for feedback control systems in underwater vehicles is well established. In its absolute form, feedback systems are used to control vehicle depth and yaw, while rate feedback (pitch or yaw rate) can be used to improve a vehicle's handling characteristics. The purpose of this report is to present a step-by-step procedure for the analysis of vehicle longitudinal feedback control systems.

The control system discussed is general in that it allows the designer to select any or all of four feedback loops (pitch rate, pitch, depth rate, and depth). Each loop is analyzed separately for this purpose. The root-locus technique is used in the analysis. To aid the engineer in the design process, a computer program has been written that will perform all the necessary computations. This program is suitable for analyzing both self-propelled and towed vehicles. Inputs to the program consists of vehicle length, speed, mass, moments of inertia, and the 30 linear hydrodynamic coefficients. Vehicle mass and moments of inertia are computed using the MIDCOHV computer program WTBAL reported in NCSL Report 220-74<sup>(1)</sup>. The hydrodynamic coefficients are computed in the MIDCOHV computer program GEORGE. The details necessary for running the program are presented in the users guide section. An example design is included to illustrate the analysis of a longitudinal feedback control system. The analysis of lateral feedback control systems is discussed in an NCSL report (2).

<sup>(1)</sup> Naval Coastal Systems Laboratory Report 220-74, The MIDCOHV Weight and Balance Computer Program (WTBAL), by K. W. Watkinson, September 1974, Unclassified.

<sup>(2)</sup> Naval Coastal Systems Laboratory Report, The Analysis of Lateral Control Systems for Self-Propelled and Towed Submarged Vehicles, by Douglas E. Humphreys, Richard W. Miller, and Larry F. Dewberry, (in publication), Unclassified

## LONGITUDINAL CONTROL SYSTEM ANALYSIS

#### BACKGROUND

A general model of a longitudinal feedback system is shown in Figure 1. The feedback loops are pitch rate ( $\theta$ ), pitch angle ( $\theta$ ), depth rate ( $\dot{z}$ ), and depth (z). The sensors are modeled as pure gains and are denoted as  $x_{\dot{\theta}}$ ,  $x_{\dot{\theta}}$ ,  $x_{\dot{z}}$ , and  $x_{\dot{z}}$ . There are two command inputs: desired depth ( $z_{\dot{\theta}}$ ) and desired pitch angle ( $z_{\dot{\theta}}$ ).

The purpose of a feedback control system is to either stabilize an unstable system, improve the system response characteristics, to control a certain variable, such as depth, or a combination of these. The desired vehicle control is achieved by successively closing each loop and varying the loop gain until the desired system dynamics are acheived. The root-locus method is used here to aid in the analysis process. For additional details on the root-locus method and the mathematics of Laplace transforms, See References 3, 4, 5, and 6 and Appendix A.

## FIRST LOOP

The inner-most loop (or first loop) is shown in Figure 2. The vehicle transfer function relating pitch rate response to stern plane input is

$$\frac{\theta}{\delta_{s}} = \frac{s\theta}{\delta_{s}} = \frac{N_{\delta_{s}}^{\theta}}{D}.$$

<sup>(3)</sup> Clark, R. N., Introduction to Automatic Control Systems, John Wiley and Sons, Inc., 1973.

<sup>(4)</sup> Hale, F. J., Introduction to Control System Analysis and Design, Prentice-Hall, Inc., 1973.

<sup>(5)</sup> Blakelock, J. H., Automatic Control of Aircraft and Missiles, John Wiley and Sons, Inc., 1965.

<sup>(6)</sup> Hildebrand, F. B., Advanced Calculus for Applications, Prentice-Hall, Inc., 1963.

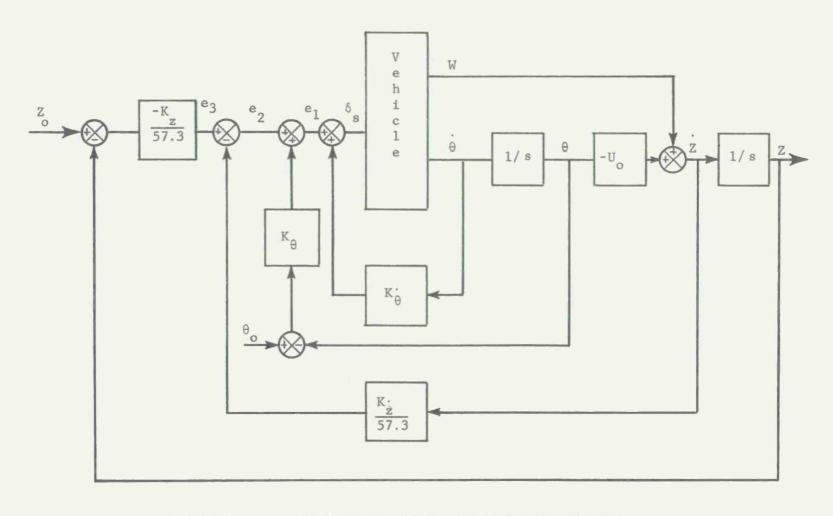


FIGURE 1. BLOCK DIAGRAM FOR LONGITUDINAL CONTROL SYSTEM

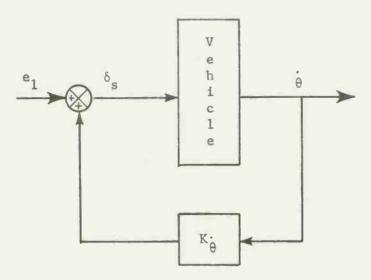


FIGURE 2. BLOCK DIAGRAM FOR THE FIRST LOOP

Where  $N_{\delta}^{\theta}$  = Pitch angle/control deflection transfer function numerator

D = Denominator of vehicle transfer function.

The numerator and denominator are functions of the vehicle hydrodynamic coefficients. Appendix B gives the expanded form of each of the vehicle transfer functions.

By solving for the closed loop transfer function,  $\dot{\theta}/e_1$ , and varying the feedback gain,  $K_{\dot{\theta}}$ , the system dynamics can be adjusted to yield the desired performance. Solving for this closed loop transfer function yields

$$\frac{\frac{\dot{\theta}}{\theta_1} = \frac{sN_{\delta_s}^{\theta}}{\frac{s}{D}} = \frac{sN_{\delta_s}^{\theta}}{D - sN_{\delta_s}^{\theta} K_{\dot{\theta}}} . \sqrt{\frac{\dot{\theta}}{S}}$$

$$1 - \frac{s}{D} K_{\dot{\theta}}$$

For stability:  $K_{\theta} \geq 0$ .

Note that although Figure 2 shows the feedback signal being added to the input signal, the system is actually a negative feedback system since the numerator,  $N_{\delta}^0$ , will always carry a negative sign.

Closing the first loop yields a new vehicle; i.e., a rate controlled vehicle, with a new characteristic equation

$$D' = D - sN_{\delta}^{\theta} K_{\theta}^{\bullet} .$$

The single prime indicates a system with one loop closure.

## SECOND LOOP

Figure 3 shows the vehicle second loop after the first loop has been closed. The vehicle transfer function with one loop closed is denoted by  $\dot{\theta}/e_1$ . The vehicle transfer functions with two loops closed is

$$\frac{\theta}{\mathbf{e}_{2}} = \frac{1/\mathbf{s} \cdot \frac{\dot{\theta}}{\mathbf{e}_{1}}}{1 + \frac{\dot{\theta}}{\mathbf{e}_{1}} \cdot \frac{\mathbf{K}\theta}{\mathbf{s}}} = \frac{\mathbf{N}_{\delta}^{\theta}}{\mathbf{D} - \mathbf{s} \mathbf{N}_{\delta}^{\theta} \cdot \mathbf{K}_{\theta}^{\bullet} + \mathbf{K}_{\theta}^{\bullet} \mathbf{N}_{\delta}^{\theta}}$$

For stability:  $K_{\theta} \leq 0$ .

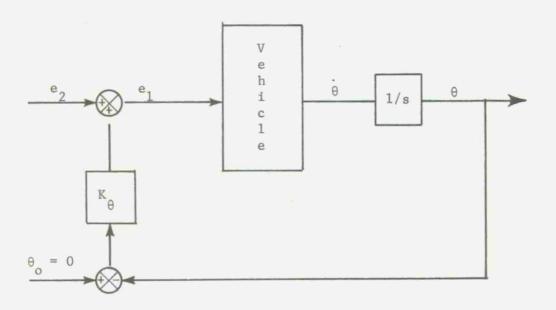


FIGURE 3. BLOCK DIAGRAM FOR THE SECOND LOOP

Note that in order to solve for the above transfer function, the pitch angle command was set to zero. Since the commanded pitch angle does not affect the vehicle characteristic response, this requirement in no way restricts the analysis capability. After the system response has been evaluated for  $\theta_0$  = 0, trajectories for other pitch angle commands can be evaluated using time domain solutions such as the one shown in Reference 7.

# THIRD LOOP

Figure 4 shows the block diagram of the third loop. The vehicle transfer function with two loops closed is denoted by  $\theta/e_2$ . To form the depth rate signal (2) requires the combination of the pitch signal and the vertical velocity according to the following equation

$$\dot{z} = w - U_0 \theta$$
,

OT

$$\frac{\cdot}{Z/\theta} = w/\theta - U_{o}.$$

The w/ $\theta$  transfer function is obtained by dividing the w/ $\delta_s$  transfer function by the  $\theta/\delta_s$  transfer function which yields

$$\frac{w/\delta_{s}}{\theta/\delta_{s}} = \frac{w}{\theta} = \frac{N_{\delta_{s}}^{w}}{N_{\delta_{s}}^{\theta}} = \frac{N_{\delta_{s}}^{w}}{N_{\delta_{s}}^{\theta}}.$$

The theoretical basis for this operation can be found in an NSRDC report (7).

<sup>(7)</sup> Naval Ship Research and Development Center, Report No. P-4-3-H-01, User's Guide NSRDC Digital Program for Simulating Submarine Motion ZZMN Revision 1.0, by Ronald W. Richard, June 1971, Unclassified.

The vehicle transfer function with three loops closed is

$$\frac{z}{e_3} = \frac{\frac{\theta}{e_2} (\frac{w}{\theta} - v_o)}{1 + \frac{\theta}{e_2} (\frac{w}{\theta} - v_o) \kappa_z^2}$$

$$\frac{z}{e_3} = \frac{\kappa_\delta^w - \kappa_\delta^\theta v_o}{1 - \kappa_\delta^\theta \kappa_\delta^\theta + \kappa_\theta^\theta \kappa_\theta^\theta + \kappa_z^\theta (\kappa_\delta^w - \kappa_\delta^\theta v_o)}$$

For stability  $K_2^* \geq 0$ .

Note that from Figure 4 this is a positive feedback system. This convention was chosen to conform with the Navy's standard motion simulation program in Hildebrand's textbook (6). The reader should note the difference between a negative feedback and a positive feedback root locus. In a negative feedback system, the locus of roots on the real axis lies to the left of an odd number of poles or zeros. In a positive feedback system, the locus of roots on the real axis lies to the right of an odd number of poles or zeros. In both cases, the locus emanates from a pole and terminates at a zero.

Also note from Figure 4 that the value for  $K_Z$  is dimensionalized by dividing it by 57.3 ( $\simeq$  4 arctan 1).

#### FOURTH LOOP

Figure 5 shows the model of the fourth and final loop. The vehicle transfer function with three loops closed is denoted by  $2/e_3$ . The vehicle transfer function with four loops closed is

$$\frac{Z}{Z_{0}} = \frac{-K_{Z} \frac{\dot{Z}}{e_{3}} \frac{1}{s}}{1 - K_{Z} \frac{\dot{Z}}{e_{3}} \frac{1}{s}}$$

$$\frac{z}{z_{o}} = \frac{-\kappa_{z}(N_{\delta_{s}}^{w} - N_{s}U_{o})}{s[D - sN_{\delta_{s}}^{\theta} K_{\theta}^{\cdot} + K_{\theta}N_{\delta_{s}}^{\theta} + K_{z}^{\cdot}(N_{\delta_{s}}^{w} - N_{\delta_{s}}^{\theta}U_{o})] - \kappa_{z}(N_{\delta_{s}}^{w} - N_{\delta_{s}}^{\theta}U_{o})}$$

<sup>(6)</sup> ibid.

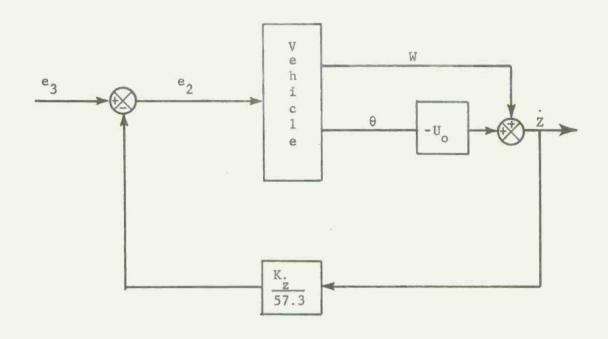


FIGURE 4. BLOCK DIAGRAM FOR THE THIRD LOOP

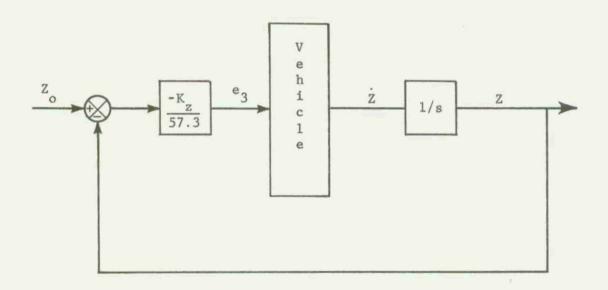


FIGURE 5. BLOCK DIAGRAM FOR THE FOURTH LOOP

For stability:  $K_Z \leq 0$ .

Note again that this is positive feedback. Again notice that the value of  $K_2$  is dimensionalized by dividing it by 57.3.

The augmented vehicle response is achieved by the commanded deflection of the stern plane. The control law that determines the stern plane position as a function of time is seen from Figure 1 as

$$\delta_{s} = K_{\theta} \dot{\theta} = (\theta_{o} - \theta) K_{\theta} - K_{z} \dot{z} - (z_{o} - z) K_{z}.$$

This conforms to the control law used in Reference 8.

#### COMPUTER PROGRAM USERS GUIDE

#### BASIC PROGRAM DESCRIPTION

This program computes the roots of the numerator and denominator for a submerged vehicle with the feedback control system described in the previous section and Appendix C. The basic inputs to the program are the vehicle nondimensional hydrodynamic coefficients, mass, and moments of inertia as defined in a SNAME publication (9). The vehicle length and speed, whether the vehicle is a towed or self-propelled body (inputed by means of a disk data file), and the range of loop gains to be analyzed (inputed systematically from an interactive terminal).

The main program computes the coefficients of the numerator and denominator equations that are shown in Appendix B. This calculation is broken down into four basic segments; one segment for each loop analyzed. The resulting polynomial equations are solved for the roots of the system by using a polynomial root factoring routine.

At the completion of the main analysis program, a data file can be automatically written for a companion program known as TIMEPLT (Appendix D). TIMEPLT is another analysis program which takes the S-domain

<sup>(8)</sup> Air Force Flight Dynamics Laboratory Research and Technology Division, Wright-Patterson Air Force Base, Analysis of Multiloop Vehicular Control Systems, by D. T. McRuer, I. L. Ashkenas, and H. R. Pass, March 1964.

<sup>(9)</sup> Society of Naval Architects and Mechanical Engineers, Nomenclature for Treating the Motion of a Submerged Body through a Fluid, 1952.

analysis and transfers it back into the time domain, complete with plot diagrams of the system output response due to standard input signals.

# INPUT REQUIREMENTS

Data input to the object program LØCSAP/ØBJECT is through the disk data file LØCSAP/DATA and from an interactive terminal. All inputs are in a free-field format. Refer to Figure 6 for an example of data file input.

## INTERACTIVE TERMINAL DATA

As described earlier, the control system analysis proceeds by closing each successive feedback loop. This is accomplished by inputing a range of loop gains for the innermost loop and then deciding on a single value before proceeding to the next system loop. At any point in the analysis, the operator is allowed to change any previous loop gains until a full set of four loop gains have been chosen. Details of the interactive terminal data can be found in the example problem (Figure 7).

#### EXAMPLE PROBLEM\*

The program is executed as follows:

??EX LØCSAP/ØBJECT \* [charge number]

FILE FILE 1 = LØCSAP/DATA; END.

At the interactive terminal, the programer is now allowed to have outputed three different data sets. The program prints the statement:

PRINT STAB DERIV, DIMRTS, TFCPRT . . .

These data sets are the vehicle nondimensional stability derivatives (input to the program from the previously mentioned data file LØCSAP/DATA), the dimensional polynomial roots, and the dimensional polynomial coefficients, respectively. A "1" input for each of the variables allows the data to be printed out; an "0" means that the printout is not desired. Following these data sets, the numerator roots (zeros) for the four control system loops are printed.

(Text Continued on Page 14)

<sup>\*</sup>This example problem is for a self-propelled vehicle, consequently some additional terms are zeroed by the program.

```
Line
           Number
                       Data Description
           0000:10.1270, 49.3330, 0,*
Record 1
Record 2
           0010: -.15020E-01, -.57700E-03,
                                               .81000E-04,/
                                               .95500E-02,/
           0020:
                   . 0
                             , -.50138E-01,
           0030:
                   . 0
                             , .0
                                                -.15709E 00,/
           0040:
                   .0
                             , -.17455E-01,
                                                -.11310E-01,/
           0050: -.16230E-02, .0
                                                . 0
           0060:
                             , -. 31545E-01,
                   . 0
                                                -.14600E-03./
           0070:
                   . 0
                             , -.13000E-03,
                                                -.15730E-02,/
           0080:
                   . 0
                             , .0
                                                 . 0
           0090:
                             , .0
                   . 0
                                                 .0
           0100:
                   .0
                             , -.27695E-01,
                                                -.12797E-01,/
           0110: .36397E-01, .19170E-02,
Note: The following information identifies the input by record,
       column, and line.
                               UQ, LB, [Type]
Record 1 0000:
                                 UØ - Vehicle Velocity (ft/sec)
                                 LB - Vehicle length (ft)
                               [Type] - 1 if a towed body,
                                        0 if self-propelled
Record 2* 0010:
                               XU
                                        , ZU
                                                  , MU
          0020:
                                        , ZW
                               XW
                                                  . MW
          0030:
                               XTHUSQ**, ZTHUSQ**, MTHUSQ**
          0040:
                               XQ
                                        , ZQ
                                                  , MQ
          0050:
                               XUD
                                        , ZUD
                                                  , MUD
          0060:
                               XWD
                                        , ZWD
                                                  , MWD
          0070:
                               XQD
                                        , ZQD
                                                  , MQD
          0080:
                               XX
                                        , ZX
                                                  , MX
          0090:
                               XZ
                                        , ZZ
                                                  . MZ
          0100:
                                        , ZDELT
                               XDELT
                                                  , MDELT
          0110:
                               M, IY
*Nondimensional Stability Derivatives (Appendix A)
**Program reads XTHUSQ(=X' U2), ZTHUSQ, MTHUSQ and converts
  to XTH( = XTHUSQ/U<sup>2</sup>), ZTH, MTH
```

FIGURE 6. EXAMPLE DATA FILE

5:LOCSAP/ØBJECT = 1 BOJ 1302 10/01/74 FROM 01/06 PRINT STAB DERIV. DIMRTS, TFCPRT...

# S N A M E NON-DIMENSIONAL LONGITUDINAL STABILITY DERIVATIVES

XU XW XTH	11 11 11	15020E- .0	Z	W		57700E-03 50138E-01	MU MW MTH	11 11 11	
XQ	=				=	17455E-01	MQ		11310E-01
XUD	=	16230E		ZUD	=	.0	MUD	=	.0
XWD	=	. 0	2	ZWD	=	31545E-01	MWD	=	14600E-03
XQD	=	. 0	2	ZQD	=	13000E-03	MQD	=	15730E-02
XX	=	. 0	. 2	XX	=	. 0	MX	=	. 0
XZ	=	. 0	2	ZZ	=	.0	MZ	=	. 0
XDELT	=	.0	7	ZDELT	=	27695E-01	MDELT	=	12797E-01
		M	. 36397E	E-01		IY =	. 19170E-	-02	2

# \*\*\*\* DENOMINATOR DS(J) \*\*\*\*

# DIMENSIONAL COEFFICIENTS

J =	1	DS =	. 0
J =	2	DS =	. 0
J =	3	DS =	.273739387358E-04
J =	4	DS =	.118877286995E-02
J =	5	DS =	.185102157604E-01
J =	6	DS =	.108587460950E 00
J =	7	DS =	.120470690538E 00

# DIMENSIONAL ROOTS

J	=	1	ROOTR =59231E-01	ROOTI =22004E-01
J	=	2	ROOTR =59231E-01	ROOTI = .22004E-01
J	=	3	ROOTR =81096E-01	ROOTI = .0
J	=	4	ROOTR =70180E 00	ROOTI = .0
J	=	5	ROOTR = .0	ROOTI = .0
J	=	6	ROOTR = .0	ROOTI = .0

\*\*\*\* X NUMERATOR \*\*\*\*

\*\*\*\*\* XS(J) COEFFICIENTS ALL ZERO \*\*\*\*\*

FIGURE 7. EXAMPLE PROBLEM (Sheet 1 of 2)

# \*\*\*\* Z NUMERATOR \*\*\*\*

# DIMENSIONAL COEFFICIENTS

J =	1	ZS =	. 0
J =	2	ZS =	153127243398E-03
J =	3	ZS =	116585064408E-01
J =	4	ZS =	128614635109E 00
J =	5	ZS =	100337496561E 00

## DIMENSIONAL ROOTS

J	=	1	ROOTR =	15883E-01	ROOTI =	. 0
J	=	2	ROOTR =	81096E-01	ROOTI =	.0
J	=	3	ROOTR =	11848E 01	ROOTI =	.0
J	=	4	ROOTR =	. 0	ROOTI =	. 0

# \*\*\*\* I NUMERATOR \*\*\*\*

# DIMENSIONAL COEFFICIENTS

J	=	1	TS	=	. 0
J	=	2	TS	=	. 0
J	=	3	TS	=	322969154535E-03
J	=	4	TS	=	548520303593E-02
J	===	5	TS	=	185293864643E-01

# DIMENSIONAL ROOTS

J = 1 J = 2 J = 3 J = 4	ROO'		.096E-01 .493E 00		ROOTI = ROOTI = ROOTI = ROOTI =	.0	
ZEROS OF TD -0.0811 0.0000	0.0000	-0.2149	0.0000	0.0000	0.0000	0.0000	0.0000
ZEROS OF T/ -0.0811		-0.2149	0.0000	0.0000	0.0000	0.0000	0.0000
		Z/Z0 -0.3690	0.0000	1.0384	0.0000	0.0000	0.0000

FIGURE 7. (Sheet 2 of 2)

#### FIRST LOOP ANALYSIS

To analyze the first loop (pitch rate), the initial value of  $K_{\theta}$  must be entered along with the step increment,  $\Delta K_{\theta}$ , and the final value of  $K_{\theta}$ . The program prints out the statement:

ENTER KTDØRG, DELKTD, KTDFIN.

The programmer must then enter the desired values as follows:

0, .5, 5.

A root locus for the inner loop will then be generated for the gain values of 0 to 5 in steps of .5 (Figure 8).

#### ENTER KTDORG, DELKTD, KTDFIN

0,	.5,5+							
	0.00	0 0220	0.0502	0.0220	0 0011	0 0000	0 3010	0 0000
	-0.0592	-0.0220	-0.0592	0.0220	-0.0811	0.0000	-0.7018	0.0000
	0.0000	0.0000	0.0000	0.0000				
	0.50	0.0000	-0.0811	0.0000	-0.0897	0,0000	0 7//7	0 0000
	-0.0407	0.0000		0.0000	-0.0097	0.0000	-0.7667	0.0000
	0.0000	0.0000	0.0000	0.0000				
	1.00	0.0000	-0.0811	0.0000	-0.1094	0.0000	0.0040	0.0000
	0.0000	0.0000	0.0000	0.0000	-0.1094	0.0000	-0.8340	0.0000
	1.50	0.0000	0.0000	0.0000				
	-0.0253	0.0000	-0.0811	0.0000	-0, 1227	0.0000	0 0000	0.0000
	0.0000	0.0000	0.0000	0.0000	-0.1227	0.0000	-0.9030	0.0000
	2.00	0.0000	0.0000	0.0000				
	-0.0217	0.0000	-0.0811	0.0000	-0.1328	0,0000	-0.9734	0.0000
	0.0000	0.0000	0.0000	0.0000	-0. 1328	0.0000	-0.9/34	0.0000
	2,50	0.0000	0.0000	0.0000				
	-0.0190	0.0000	-0.0811	0.0000	-0.1409	0.0000	-1.0449	0.0000
	0.0000	0.0000	0.0000	0,0000		0.000	2.0445	0.0000
	3.00							
	-0.0170	0.0000	-0.0811	0.0000	-0.1475	0.0000	-1.1172	0.0000
	0.0000	0.0000	0.0000	0.0000				
	3.50							
	-0.0154	0.0000	-0.0811	0.0000	-0.1531	0.0000	-1.1901	0.0000
	0.0000	0.0000	0.0000	0.0000				
	. 4.00							
	-0.0141	0.0000	-0.0811	0.0000	-0.1578	0.0000	-1.2637	0.0000
	0.0000	0.0000	0.0000	0.0000				
	4.50							
	-0.0129	0.0000	-0.0811	0.0000	-0.1618	0.0000	-1.3376	0.0000
	0.0000	0.0000	0.0000	0.0000				
	5.00							
	-0.0120	0.0000	-0.0811	0.0000	-0.1654	0.0000	-1.4119	0.0000
	0.0000	0.0000	0.0000	0.0000				

FIGURE 8. EXAMPLE PROBLEM: FIRST LOOP ANALYSIS

Each root is listed as a real and imaginary pair, read from left to right, top and bottom. For example, at a gain value  $K_{\theta} = 0.00$  (first three digit number printed) the denominator roots (poles) are

Real	Imaginary
0592	-j .0220
0592	+j .0220
0811	10
7018	10

While the loop zeros (previously printed out) are

Real	Imaginary
-,0811	10
2149	<b>j</b> 0
0.0	10.0

The two zero value roots for each are not shown since this example is for a self-propelled vehicle; for a towed vehicle they would have a nonzero value.

Figure 9 is a plot of the root locus for this loop.

After printing the value for the roots over the gain range specified, the program will then print out the next statement:

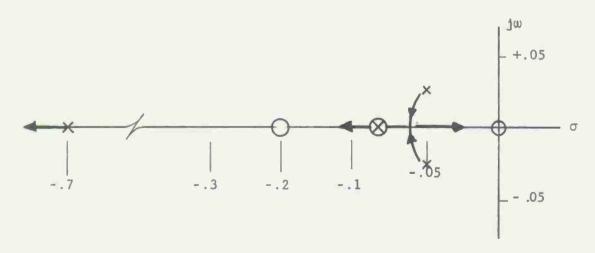


FIGURE 9. ROOT LOCUS FOR THE FIRST LOOP

DØ YØU WANT TØ CØTINUE KTD R.LØCUS.

The programmer must enter:

- 0 if he desires to go on to the second loop.
- 1 if he desires to continue the root locus in the first loop.

If 1 is entered, the program will again ask for values of KTD $\emptyset$ RG, DELKTD, KTDFIN.

If 0 is entered, the program will ask for the desired first loop gain by printing ENTER KTD. The programmer must enter the selected first loop gain.

SECOND, THIRD, AND FOURTH LOOPS

The above procedure is repeated for the next three loops. When new values are requested at the end of each root locus, three options are available. This is to allow the programmer to go back to any desired inside loop at any point in the program. For example, if after completing the root locus in the second loop, the programmer may wish to reanalyze the first loop based on what he learned from the second loop root locus. This is accomplished as follows. The program prints out the statement

DO / YØU WANT NEW KTD,  $0 = N\emptyset$ , 1 = ENT, 2 = ENT & CØMP, KTD NØW = 1 after the second loop root locus is complete. The programmer must enter

- 0 If he desires to go to the third loop,
- 1 If he desires to change the value of the first loop gain,
- 2 If he desires to go back to the first loop and recompute the root locus.

This return option is available at the completion of each loop's locus.

For the fourth loop, two gain values are printed, the loop gain and the system gain. The system gain is defined as

$$GAIN = K_Z \frac{ZS(5)}{DS(5)}$$

for self-propelled vehicles (see Appendix B for definition of terms). The gain is the steady state value for depth, Z, for a unit step in depth command,  $\mathbf{Z}_0$ . Normally, it is desirable for this gain value to be equal to unity.

The remainder of the vehicle control system analysis follows as shown in an example problem (Figure 10), along with root locus plots for the second, third, and fourth loops (Figures 11, 12, and 13).

When the programmer is satisfied with the analysis and has selected gain values for all four loops, the program prints out

DØ YØU WANT A TIMEPLT.

By inputing a 1 (yes) to the LØCSAP program, a data file is automatically created which will later be utilized by the program TIMEPLT. The root values to be passed to the file are determined by the operators answer to the next two questions asked of him by the program.

ENTER KTD, KT, KZD, KZ, GAMP

TIMEPLT FØR WHICH LØØP .

The K values are the individual loop gains, and the variable GAMP is indicative of the type and magnitude of the standard test signal to be inputed to the system. Answering the question as to which loop, determines which loop output will be plotted by the companion program. This analysis can be repeated as many times as desired, until the operator answers N $\emptyset$  (0) to the question:

DØ YØU WANT ANØTHER TIMEPLT,

at which point the root-locus program is terminated.

#### CONCLUSIONS

A computer program was written utilizing the root-locus technique to analyze a longitudinal feedback control system. An example problem is included illustrating the use of this program.

To date, this analysis program has been utilized in the design of control systems for swimmer delivery vehicles, a submarine, and towed mine-hunting vehicles.

```
DO YOU WANT TO CONTINUE KTD R. LOCUS
0+
ENTER KTD
1+
ENTER KTORG, DELKT, KTFIN
0,-.5,-5
   0.00
                                           0.0000 -0.8340 0.0000
  -0.0307
         0.0000 - 0.0811 0.0000 - 0.1094
  0.0000 0.0000 0.0000 0.0000
  -0.50
  -0.1150 -0.1130 -0.1150 0.1130 -0.0811
                                           0.0000 - 0.7441
                                                           0.0000
         0.0000 0.0000 0.0000
  0.0000
  -1.00
  -0.1724 -0.1651 -0.1724 0.1651 -0.0811
                                           0.0000 - 0.6292
                                                           0.0000
  0.0000 0.0000 0.0000 0.0000
  -1.50
 -0.0811 0.0000 -0.2584 -0.2186
                                  -0.2584 0.2186 -0.4572
                                                           0.0000
         0.0000 0.0000 0.0000
  0.0000
  -2.00
  -0.0811 0.0000 -0.3110 0.0000 -0.3315 -0.3342 -0.3315
                                                           0.3342
  0.0000
         0.0000 0.0000 0.0000
  -2.50
  -0.0811 0.0000 -0.2726
                           0.0000 - 0.3508 - 0.4364 - 0.3508
                                                           0.4364
  0.0000 0.0000 0.0000 0.0000
  -3.00
         0.0000 - 0.2565 0.0000 - 0.3588 - 0.5185 - 0.3588
  -0.0811
                                                           0.5185
  0.0000 0.0000 0.0000 0.0000
  -3.50
  -0.0811
         0.0000 - 0.2476
                           0.0000 - 0.3632 - 0.5888 - 0.3632
                                                           0.5888
  0.0000 0.0000 0.0000 0.0000
  -4.00
          0.0000 - 0.2410
                                  0.3661 0.6514 -0.3661
  0.0811
                           0.0000
                                                           0.6514
          0.0000 0.0000 0.0000
  0.0000
  -4.50
  -0.0811 0.0000 -0.2379 0.0000 -0.3681
                                           -0.7083 -0.3681 0.7083
   0.0000 0.0000 0.0000 0.0000
  -5.00
  -0.0811
           0.0000 - 0.2349
                         0.0000 -0.3696 -0.7609 -0.3696 0.7609
   0.0000
           0.0000
                 0.0000
                           0.0000
DO YOU WANT NEW KTD, 0=NO, 1=ENT, 2=ENT&COMP, KTD NOW= 1.00
DO YOU WANT TO CONTINUE KT R. LOCUS
0+
```

FIGURE 10. EXAMPLE PROBLEM: SECOND, THIRD AND FOURTH LOOP ANALYSIS (Sheet 1 of 5)

```
ENTER KT
-1 \leftarrow
ENTER KZDORG, DELKZD, KZDFIN
0, .5, 5 \leftarrow
    0.00
  -0.1724 -0.1651 -0.1724
                             0.1651 - 0.0811 0.0000 - 0.6292
                                                                  0.0000
            0.0000
                   0.0000
                              0.0000
   0.0000
    0.50
 -0.0811
         0.0000 - 0.3992
                              0.0000
                                     -0.0792 -0.6952 -0.0792
                                                                  0.6952
   0.0000
            0.0000
                   0.0000
                             0.0000
   1.00
                              0.0000
                                       0.1213 - 0.9539
                                                         0.1213
                                                                  0.9539
 -0.0811
            0.0000 - 0.3839
  0.0000
            0.0000
                   0.0000
                              0.0000
   1.50
  -0.0811
            0.0000 - 0.3788
                              0.0000
                                       0.3270 -1.1186
                                                         0.3270
                                                                  1.1186
   0.0000
            0.0000
                   0.0000
                              0.0000
    2.00
 -0.0811
            0.0000 - 0.3764
                              0.0000
                                       0.5340 - 1.2271
                                                         0.5340
                                                                  1.2271
   0.0000
            0.0000
                   0.0000
                              0.0000
    2.50
                              0.0000
                                       0.7415 - 1.2938
                                                         0.7415
                                                                  1.2938
  -0.0811
            0.0000 - 0.3749
   0.0000
            0.0000
                   0.0000
                              0.0000
    4.00
            0.0000 - 0.3739
                              0.0000
                                       0.9492 - 1.3249
                                                         0.9492
                                                                  1.3249
  -0.0811
   0.0000
            0.0000
                   0 0000
                              0.0000
    3.50
  -0.0811
            0.0000 - 0.3732
                              0.0000
                                       1.1571 -1.3229
                                                         1.1571
                                                                  1.3229
   0.0000
            0.0000
                   0.0000
                              0.0000
    3.00
 -0.0811
            0.0000 - 0.3726
                              0.0000
                                       1.3650 -1.2877
                                                         1.3650
                                                                  1.2877
   0.0000
            0.0000
                   0.0000
                              0.0000
    4.50
                              0.0000
  -0.0811
            0.0000 - 0.3722
                                     1.5731 -1.2164
                                                         1.5731
                                                                  1.2164
   0.0000
            0.0000
                   0.0000
                             0.0000
    5.00
            0.0000 - 0.3719
                             0.0000
                                     1.7811 -1.1019
                                                         1.7811
  -0.0811
                                                                  1.1019
   0.0000
            0.0000
                    0.0000
                              0.0000
DO YOU WANT NEW KTD, KTD NOW =
                                1.00
DO YOU WANT NEW KT, KT NOW =
                             -1.00
DO YOU WANT TO CONTINUE KZD R. LOCUS
ENTER KZDORG, DELKZD, KZDFIN
0, -.5, -3 \leftarrow
```

FIGURE 10. (Sheet 2 of 5)

```
0.00
 -0.1724 -0.1651 -0.1724 0.1651 -0.0811 0.0000 -0.6292 0.0000
  0.0000 0.0000 0.0000 0.0000
  -0.50
 -0.0811 0.0000 0.2740 0.0000 -0.3410
                                        0.0000 -1.3235 0.0000
  0.0000 0.0000 0.0000 0.0000
  -1.00
 -0.0811 0.0000 -0.3547 0.0000 0.4253
                                         0.0000 - 1.8776 0.0000
  0.0000 0.0000 0.0000 0.0000
  -1.50
 -0.3594 0.0000 0.5174 0.0000 -0.0811 0.0000 -2.3814
                                                        0.0000
  0.0000 0.0000 0.0000 0.0000
  -2.00
 -0.0811 0.0000 -0.3617 0.0000 0.5822 0.0000 -2.8603 0.0000
  0.0000 0.0000 0.0000 0.0000
  -2.50
 -0.0811 0.0000 -0.3632 0.0000
                                 0.6311 0.0000 -3.3242
                                                        0.0000
 0.0000 0.0000 0.0000 0.0000
  -3.00
 -0.0811 0.0000 -0.3641 0.0000 0.6698 0.0000 -3.7783 0.0000
  0.0000 0.0000 0.0000 0.0000
DO YOU WANT NEW KTD, KTD NOW = 1.00
DO YOU WANT NEW KT, KT NOW = -1.00
DO YOU WANT TO CONTINUE KZD R. LOCUS
0+
ENTER KZD
0,.5,5 \leftarrow
   0.00
GAIN = 0.000
 -0.1724 -0.1651 -0.1724 0.1651 -0.0811 0.0000 -0.6292 0.0000
  0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
   0.50
GAIN = -2.710
 -0.0811 0.0000 -0.3803 0.0000 0.4495 0.0000 -0.5216 -0.8133
 -0.5216 0.8133 0.0000 0.0000 0.0000
                                        0.0000
  1.00
GAIN = -5.421
 -0.0811 0.0000 -0.3745 0.0000 0.5577
                                         0.0000 - 0.5787 - 1.0922
 -0.5787 1.0922 0.0000 0.0000 0.0000
                                        0.0000
  1.50
GAIN = -8.131
 -0.0811 0.0000 0.6230 0.0000 -0.3726
                                        0.0000 - 0.6122 - 1.2989
 -0.6122 1.2989 0.0000 0.0000 0.0000
                                        0.0000
```

FIGURE 10. (Sheet 3 of 5)

```
2.00
GAIN = -10.841
 2.50
GAIN = -13.552
 -0.0811 0.0000 -0.3711 0.0000 0.7041 0.0000 -0.6535 -1.6204
 -0.6535 1.6204 0.0000 0.0000 0.0000
                                       0.0000
  3.00
GAIN = -16.262
 -0.0811 0.0000 -0.3708 0.0000
                                       0.0000 - 0.6677 - 1.7552
                                0.7321
 -0.6677 1.7552 0.0000 0.0000 0.0000
                                       0.0000
  3.50
GAIN = -18.972
 -0.0811 0.0000 -0.3705 0.0000 0.7552 0.0000 -0.6794 -1.8788
 -0.6794 1.8788 0.0000 0.0000 0.0000 0.0000
  4.00
GAIN = -21.683
 -0.0811 0.0000 -0.3703 0.0000 0.7746 0.0000 -0.6892 -1.9937
 -0.6892 1.9937 0.0000 0.0000 0.0000 0.0000
  4.50
GAIN = -24.393
-0.0811 0.0000 -0.3702 0.0000 0.7913 0.0000 -0.6976 -2.1014
-0.6976 2.1014 0.0000 0.0000 0.0000 0.0000
  5.00
GAIN = -27.103
 -0.0811 0.0000 -0.3701 0.0000 0.8058 0.0000 -0.7049 -2.2032
 -0.7049 2.2032 0.0000 0.0000 0.0000 0.0000
DO YOU WANT NEW KTD, KTD NOW = 1.00
DO YOU WANT NEW KT. KT NOW = -1.00
DO YOU WANT NEW KZD, KZD NOW = 0.00
DO YOU WANT TO CONTINUE KZ R. LOCUS
1+
ENTER KZORG, DELKZ, KZFIN
0, -.5, -3 \leftarrow
  0.00
GAIN = 0.000
  -0.1724 -0.1651 -0.1724 0.1651 -0.0811 0.0000 -0.6292 0.0000
   0.0000 0.0000 0.0000 0.0000 0.0000
   -0.50
GAIN = 2.710
  -0.0811 0.0000 -0.3586 0.0000 0.3000 -0.5254 0.3000 0.5254
  -1,2154 0,0000 0,0000 0,0000 0,0000 0,0000
   -1.00
                          FIGURE 10.
                         (Sheet 4 of 5)
```

```
GAIN = 5.421
  -0.0811 0.0000 -0.3637 0.0000 0.4504 -0.6146 0.4504 0.6146
  -1.5113
           0.0000 0.0000 0.0000 0.0000 0.0000
   -1.50
GAIN = 8.131
  -0.0811 0.0000 0.5629 -0.6620 0.5629
                                            0.6620 -0.3654 0.0000
  -1.7345 0.0000 0.0000 0.0000 0.0000
                                           0.0000
   -2.00
GAIN = 10.841
  -0.0811 0.0000 0.6564 -0.6901 0.6564
                                            0.6901 -0.3663
                                                            0.0000
  -1.9206 0.0000 0.0000 0.0000 0.0000 0.0000
   -2.50
GAIN = 13.552
   0.7380 -0.7066 0.7380 0.7066 -0.0811 0.0000 -0.3668 0.0000
  -2.0832 0.0000 0.0000 0.0000 0.0000
                                           0.0000
   -3.00
GAIN = 16.262
                                   0.8112 -0.7151 0.8112 0.7151
  -0.0811 0.0000 -0.3672
                           0.0000
  -2.2293 0.0000 0.0000
                           0.0000 0.0000
                                          0.0000
DO YOU WANT NEW KTD, KTD NOW = 1.00
0+
DO YOU WANT NEW KT, KT NOW = -1.00
DO YOU WANT NEW KZD, KZD NOW = 0.00
0+
DO YOU WANT TO CONTINUE KZ R. LOCUS
DO YOU WANT A TIMEPLT
ENTER KTD, KT, KZD, KZ, GAMP
1,-1,0,0,10
TIMEPLT FOR WHICH LOOP; ENTER 1=1ST, 2=2ND, 3=3RD, 4=4TH
DO YOU WANT ANOTHER TIMEPLT
0+
PROCESSOR TIME =
                  15 SEC
                             $ 0.60
                             $ 0.46
I/O TIME
              222
                  23 SEC
PRORATED TIME
              =
                  249 SEC
                             $ 2.49
                            $ 3.55
                  TOTAL COST
```

LOCSAP/MILLER = 1 EOJ 1326

FIGURE 10. (Sheet 5 of 5)

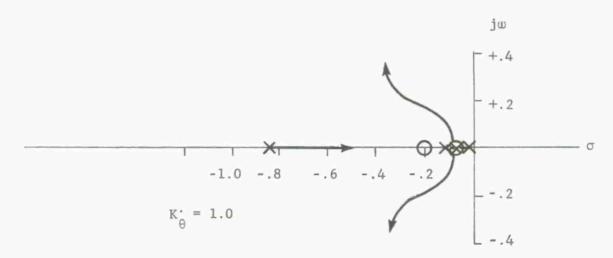


FIGURE 11 ROOT LOCUS FOR THE SECOND LOOP

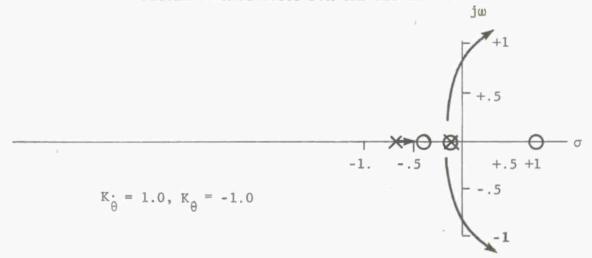


FIGURE 12. ROOT LOCUS FOR THE THIRD LOOP  $j\omega$ 

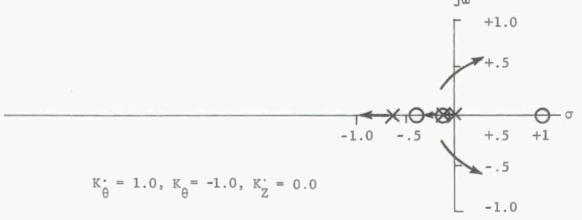


FIGURE 13. ROOT LOCUS FOR THE FOURTH LOOP

		,
'	<b>b</b>	

#### APPENDIX A

# SOME NOTES ON THE CONSTRUCTION AND INTERPRETATION OF ROOT LOCUS

A physical system can be represented by a block diagram composed of individual blocks that represent the various components of the system as shown in Figure Al. Each block is described by one or more

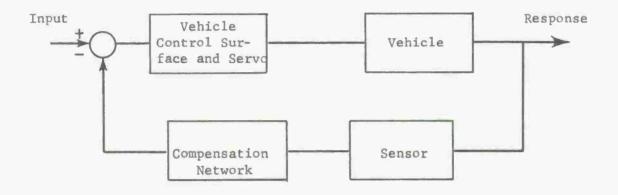


FIGURE A1. A TYPICAL BLOCK DIAGRAM

differential equations according to Newton's Second Law of Motion or its electrical equivalent. Combining the characteristics of each block to form the characteristics of the overall system is quite difficult because a signal is modified in both phase and amplitude in going through each block. By applying the Laplace transform

$$F(s) = \int_{0}^{\infty} f(t)e^{-st} dt$$

to the describing differential equations, one obtains an algebraic representation for each block in the system. It is then convenient to arrange this representation in the form of a transfer function; i.e., as a ratio of block response to block excitation. These transfer functions can be be multiplied together to yield system response to system excitation. It is a relatively straightforward procedure because each transfer function is merely a ratio of polynomials in the Laplace operator s.

Once the transfer functions for each of the blocks have been formed, it is then necessary to examine the effects of changing various unknown system parameters, such as feedback gain on the system dynamics. The root-locus diagram was developed to facilitate such an analysis. As the name implies, it shows on one figure the trajectory that the frequency and damping characteristic modes follow as system parameters are changed.

Consider the transfer function

$$\frac{0}{I} = \frac{K(s + a)(s^2 + bs + c)}{s(s + d)(s + e)(s^2 + fs + g)}.$$

The denominator of the transfer function represents the characteristic equation of the system; e.g., the equation describing the free motion of the system (the response independent of control input). It is responsible for the general solution of the system of differential equations. The particular solution comes from the numerator.

It will be observed that all values of s which make the denominator zero are solutions of the characteristic equation and therefore contirbute a term of the e<sup>\( \) to the time response. Since for these roots the transfer function is undefined, denominator roots are called poles. Numerator roots are appropriately called zeros. It is customary to plot these poles and zeros on a graph whose abscissa is the real part of s and whose ordinate is the imaginary part. Poles are commonly depicted as x's and zeros are 0's. A first order root; e.g., (s + d), will always lie on the abscissa. A second order system has two roots. They may be real, in which case they lie on the abscissa, or they may be complex, in which case they are placed equidistant above and below the abscissa.</sup>

Any pole which lies in the right half s-plane represents an unstable motion. Zeros in the right half plane are significant in terms of the type motion only if the system depicted is a feedback system. In this case the zeros represent the location of the poles when the feedback gain is made infinite. For zeros in the right half plane then, the system will become unstable at some finite value of feedback gain. Knowledge of the location of the basic vehicle zeros is needed by designers to combine the control system characteristics with those of the vehicle to obtain the desired response without unexpected instabilities. Note also that a zero placed on top of a pole will eliminate the motion caused by that pole from the time history of the particular variable associated with the numerator  $(\theta \text{ in } \theta/\delta_{\mathbf{r}})$  for example) but from no other time history.

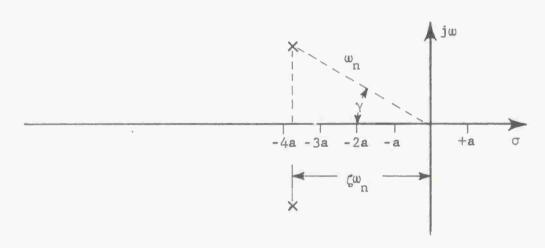
A pole located at s=-3, for example, means that there is contribution to the time history given by  $e^{-3t}$ . Thus, the further to the left the pole, the more rapid is the subsidence. Conversely, a pole at s=3 means the motion has an unstable component described by  $e^{3t}$ .

Stable oscillatory modes, it will be recalled, have roots which can be expressed by

$$s_1, s_2 = -\zeta \omega_n + j \omega_n \sqrt{1 - \zeta^2}$$

Figure A2 indicates how varying either frequency or damping ratio separately moves the poles. It also shows that the product  $\zeta \omega_n$  determines the time for an oscillation to decay to half amplitude. When  $\zeta \omega_n = 0.591$ , the oscillation will decay to half amplitude in 1 second. Smaller values of the product mean the time to damp to half amplitude is longer.

For further details on the construction and interpretation of root locus diagrams refer to *Introduction to Automatic Control Systems*, John Wiley and Son, 1962.



ζ = Damping Ratio = cos γ

 $\omega_n$  = Undamped Natural Frequency

 $\zeta w_n = Total Damping$ 

 $t_{ss}$  = Time to reach 0.95 steady state value = 3.0/ $\zeta \omega_{p}$ 

 $t_{1/2}$  Time to damp to half amplitude = 0.69/ $\zeta \omega_{\rm p}$ 

 $t_2$  = Time to double amplitude (unstable systems only) = 0.69/ $\omega_n$ 

FIGURE A2. IMPORTANT FEATURES OF ROOT-LOCUS DIAGRAM

(Reverse Page A-4 Blank)

No. of the second secon	
1	

#### APPENDIX B

# EXPRESSIONS FOR THE LONGITUDINAL TRANSFER FUNCTION COEFFICIENTS

The longitudinal characteristic equation is

$$\Delta_{\text{Long}} = As^{4} + Bs^{3} + Cs^{2} + Ds' + E$$

where

$$A = (m' - \chi'_{ii})(m' - Z'_{iir})(I'_{y} - M'_{ij}) - \chi'_{iir}M'_{ii}Z'_{ij}$$

$$- Z'_{ii}M'_{iir}\chi'_{ij} - (m' - Z'_{iir})M'_{ii}\chi'_{ij}$$

$$- Z'_{ii}\chi'_{iir}(I'_{y} - M'_{ij}) - M'_{iir}(m' - \chi'_{ii})Z'_{ij}.$$

$$B = -(m' - \chi'_{ii})(m' - Z'_{iir})M'_{q} - Z'_{iir}(m' - \chi'_{ii})(I'_{y} - M'_{ij})$$

$$- \chi'_{ii}(m' - Z'_{iir})(I'_{y} - M'_{ij}) - \chi'_{iir}M'_{ii}(Z'_{q} + m')$$

$$- M'_{iir}\chi'_{ij}Z'_{ij} - M'_{iir}\chi'_{ij}Z'_{ij} - Z'_{iir}M'_{iir}\chi'_{q} - Z'_{iir}M'_{iir}\chi'_{ij}$$

$$- Z'_{ii}M'_{iir}\chi'_{ij} - (m' - Z'_{iir})M'_{ii}\chi'_{q} - M'_{ii}(m' - Z'_{iir})\chi'_{ij}$$

$$+ M'_{iir}Z'_{ir}\chi'_{ij} + Z'_{iir}\chi'_{ir}M'_{q} - Z'_{ir}\chi'_{ir}(I'_{y} - M'_{ij})$$

$$- Z'_{ii}\chi'_{ir}(I'_{y} - M'_{ij}) - M'_{iir}(m' - \chi'_{ii})(Z'_{q} + m')$$

$$- M'_{iir}(m' - \chi'_{ii})Z'_{ij} + M'_{iir}\chi'_{ir}Z'_{ij}.$$

$$C = -(m' - \chi'_{ii})(m' - Z'_{iir})M'_{0} + Z'_{iw}(m' - \chi'_{ii})M'_{q}$$

$$+ \chi'_{u}(m' - Z'_{iir})M'_{q} + Z'_{uv}\chi'_{u}(I'_{y} - M'_{i}) - \chi'_{iir}M'_{ii}Z'_{0}$$

$$- M'_{u}\chi'_{iir}(Z'_{q} + m') - M'_{ii}\chi'_{w}(Z'_{q} + m') - Z'_{ii}M'_{iir}\chi'_{0}$$

$$- Z'_{ii}M'_{ur}\chi'_{q} - Z'_{u}M'_{iir}\chi'_{q} - Z'_{u}M'_{ur}\chi'_{q}$$

$$- (m' - Z'_{iir})M'_{ii}\chi'_{0} - M'_{u}(m' - Z'_{iir})\chi'_{q} + M'_{ii}Z'_{ur}\chi'_{q}$$

$$+ Z'_{ur}M'_{u}\chi'_{q} + Z'_{ii}\chi'_{iir}M'_{0} + Z'_{u}\chi'_{iir}M'_{q} + Z'_{ii}\chi'_{ur}M'_{q}$$

$$- \chi'_{ur}Z'_{u}(I'_{y} - M'_{i}) - M'_{iir}(m' - \chi'_{i})Z'_{0} - M'_{ur}(m' - \chi'_{ii})(Z'_{q} + m')$$

$$+ M'_{iir}\chi'_{u}(Z'_{q} + m') + \chi'_{u}M'_{ur}Z'_{q} - M'_{u}\chi'_{ur}Z'_{q} .$$

$$D = Z'_{w}M'_{\phi}(m'-X'_{\dot{u}}) + X'_{u}(m'-Z'_{\dot{w}})M'_{\phi} - Z'_{w}X'_{u}M'_{g}$$

$$-M'_{u}X'_{\dot{w}}Z'_{\phi} - M'_{\dot{u}}X'_{w}Z'_{\phi} - M'_{u}X'_{w}(Z'_{g}+m')$$

$$-Z'_{\dot{u}}M'_{w}X'_{\phi} - Z'_{u}M'_{\dot{w}}X'_{\phi} - Z'_{u}M'_{w}X'_{g}$$

$$-M'_{u}(m'-Z'_{\dot{w}})X'_{\phi} + M'_{\dot{u}}Z'_{w}X'_{\phi} + Z'_{w}M'_{u}X'_{g}$$

$$+Z'_{u}X'_{\dot{w}}M'_{\phi} + Z'_{\dot{u}}X'_{w}M'_{\phi} + X'_{w}Z'_{u}M'_{g}$$

$$-M'_{w}(m'-X'_{\dot{u}})Z'_{\phi} + M'_{\dot{w}}X'_{u}Z'_{\phi} + M'_{w}X'_{u}(Z'_{g}+m').$$

$$E = -Z'_{\mu\nu} X'_{\mu} M'_{\theta} - M'_{\mu} X'_{\mu\nu} Z'_{\theta} - Z'_{\mu} M'_{\mu\nu} X'_{\theta}$$

$$+ Z'_{\mu\nu} M'_{\mu} X'_{\theta} + X'_{\mu\nu} Z'_{\mu} M'_{\theta} + X'_{\mu} M'_{\mu\nu} Z'_{\theta}.$$

The pitch response transfer function is

$$\frac{\theta}{\delta_{s}} = \frac{N_{\delta_{s}}^{\theta}}{\Delta_{Long}} = \frac{A_{\theta_{s}}^{2} + B_{\theta_{s}} + C_{\theta_{s}}}{\Delta_{Long}}$$

where

$$A_{\phi} = M'_{\delta_{e}}(m' - \chi'_{ii})(m' - Z'_{ii'}) + Z'_{\delta_{e}}\chi'_{ii'}M'_{ii} + \chi'_{\delta_{e}}Z'_{ii}M'_{ii'}$$

$$-M'_{\delta_{e}}\chi'_{ii'}Z'_{ii} + \chi'_{\delta_{e}}(m' - Z'_{ii'})M'_{ii} + Z'_{\delta_{e}}M'_{ii'}(m' - \chi'_{ii}).$$

$$\begin{split} \mathcal{B}_{\theta} &= -M_{\delta_{e}}'(m' - \chi_{ii}') \mathcal{Z}_{ii'}' - M_{\delta_{e}}' \chi_{ii}' (m' - \mathcal{Z}_{ii'}') + \mathcal{Z}_{\delta_{e}}' \chi_{ii'}' M_{ii}' \\ &+ \mathcal{Z}_{\delta_{e}}' \chi_{ii'}' M_{ii}' + \chi_{\delta_{e}}' \mathcal{Z}_{ii}' M_{ii'}' + \chi_{\delta_{e}}' \mathcal{Z}_{ii}' M_{ii'}' \\ &- M_{\delta_{e}}' \chi_{ii'}' \mathcal{Z}_{ii}' - M_{\delta_{e}}' \chi_{ii'}' \mathcal{Z}_{ii}' + \chi_{\delta_{e}}' (m' - \mathcal{Z}_{ii'}') M_{ii}' \\ &- \chi_{\delta_{e}}' \mathcal{Z}_{ii'}' M_{ii}' - \mathcal{Z}_{\delta_{e}}' M_{ii'}' \chi_{ii}' + \mathcal{Z}_{\delta_{e}}' M_{ii'}' (m' - \chi_{ii}') \; . \end{split}$$

$$C_{\phi} = M_{\delta_{e}}^{'} X_{\mu}^{'} Z_{\mu\nu}^{'} + Z_{\delta_{e}}^{'} X_{\mu\nu}^{'} M_{\mu}^{'} + X_{\delta_{e}}^{'} Z_{\mu}^{'} M_{\mu\nu}^{'} - M_{\delta_{e}}^{'} X_{\mu\nu}^{'} Z_{\mu}^{'} - X_{\delta_{e}}^{'} Z_{\mu\nu}^{'} M_{\mu}^{'} - Z_{\delta_{e}}^{'} M_{\mu\nu}^{'} X_{\mu}^{'} .$$

The vertical velocity transfer function is

$$\frac{W'}{\delta_{s}} = \frac{N_{\delta_{s}}^{W}}{\Delta_{\text{Long}}} = \frac{A_{W}s'^{3} + B_{W}s'^{2} + C_{W}s' + D_{W}}{\Delta_{\text{Long}}}$$

where

$$A_{uv} = Z'_{\delta_{e}}(m' - X'_{ii})(I'_{y} - M'_{ij}) + X'_{\delta_{e}}M'_{ii}Z'_{ij} + M'_{\delta_{e}}Z'_{ii}X'_{ij}$$

$$-Z'_{\delta_{e}}M'_{ii}X'_{ij} + X'_{\delta_{e}}Z'_{ii}(I'_{y} - M'_{ij}) + M'_{\delta_{e}}(m' - X'_{ii})Z'_{ij}.$$

$$\begin{split} B_{w} &= - Z_{\delta_{e}}^{'}(m' - X_{\dot{u}}^{'}) M_{q}^{'} - Z_{\delta_{e}}^{'} X_{u}^{'} (I_{y} - M_{\dot{q}}^{'}) \\ &+ X_{\delta_{e}}^{'} M_{u}^{'} Z_{\dot{q}}^{'} + X_{\delta_{e}}^{'} M_{\dot{u}}^{'} (Z_{q}^{'} + m') \\ &+ M_{\delta_{e}}^{'} Z_{\dot{u}}^{'} X_{q}^{'} + M_{\delta_{e}}^{'} Z_{u}^{'} X_{\dot{q}}^{'} \\ &- Z_{\delta_{e}}^{'} M_{\dot{u}}^{'} X_{q}^{'} - Z_{\delta_{e}}^{'} M_{u}^{'} X_{\dot{q}}^{'} \\ &- X_{\delta_{e}}^{'} Z_{\dot{u}}^{'} M_{q}^{'} + X_{\delta_{e}}^{'} Z_{u}^{'} (I_{y}^{'} - M_{\dot{q}}^{'}) \\ &+ M_{\delta_{e}}^{'} (m' - X_{\dot{u}}^{'}) (Z_{q}^{'} + m') - M_{\delta_{e}}^{'} X_{u}^{'} Z_{\dot{q}}^{'} \\ &+ M_{\delta_{e}}^{'} (m' - X_{\dot{u}}^{'}) (Z_{q}^{'} + m') - M_{\delta_{e}}^{'} X_{u}^{'} Z_{\dot{q}}^{'} \end{split}$$

$$C_{\mu\nu} = -Z_{\delta_{e}}'(m' - X_{ii}')M_{\phi}' + Z_{\delta_{e}}'X_{ii}M_{q}' + X_{\delta_{e}}'M_{ii}Z_{\phi}'$$

$$+ X_{\delta_{e}}'M_{ii}'(Z_{q}' + m') + M_{\delta_{e}}'Z_{ii}'X_{\phi}' + M_{\delta_{e}}'Z_{ii}'X_{q}'$$

$$- Z_{\delta_{e}}'M_{ii}'X_{\phi}' - Z_{\delta_{e}}'M_{ii}'X_{q}' - X_{\delta_{e}}'Z_{ii}M_{\phi}' - X_{\delta_{e}}'Z_{ii}M_{q}'$$

$$+ M_{\delta_{e}}'(m' - X_{ii}')Z_{\phi}' - M_{\delta_{e}}'X_{ii}'(Z_{q}' + m') .$$

$$D_{\mu\nu} = Z_{\delta_{e}}^{'} X_{\mu}^{'} M_{\phi}^{'} + X_{\delta_{e}}^{'} M_{\mu}^{'} Z_{\phi}^{'} + M_{\delta_{e}}^{'} Z_{\mu}^{'} X_{\phi}^{'}$$
$$- Z_{\delta_{e}}^{'} M_{\mu}^{'} X_{\phi}^{'} - X_{\delta_{e}}^{'} Z_{\mu}^{'} M_{\phi}^{'} - M_{\delta_{e}}^{'} X_{\mu}^{'} Z_{\phi}^{'}.$$

The forward speed transfer function is

$$\frac{\underline{U'}}{\delta_{s}} = \frac{N_{\delta_{s}}^{U}}{\Delta_{Long}} = \frac{A_{\underline{U}}s'^{3} + B_{\underline{U}}s'^{2} + C_{\underline{U}}s' + D_{\underline{U}}}{\Delta_{Long}}$$

where

$$A_{\mu} = \chi'_{\delta_{e}}(m' - Z'_{ii})(I'_{y} - M'_{\dot{q}}) + M'_{\delta_{e}}\chi'_{ii}Z'_{\dot{q}} + Z'_{\delta_{e}}M'_{ii}\chi'_{\dot{q}}$$

$$+ M'_{\delta_{e}}(m' - Z'_{ii})\chi'_{\dot{q}} + Z'_{\delta_{e}}\chi'_{ii}(I'_{y} - M'_{\dot{q}}) - \chi'_{\delta_{e}}M'_{ii}Z'_{\dot{q}}.$$

$$\begin{split} \mathcal{B}_{\mu} &= -\chi'_{\delta_{e}}(m' - Z'_{iw})M'_{q} - \chi'_{\delta_{e}}(I'_{y} - M'_{\dot{q}})Z'_{w} \\ &+ M'_{\delta_{e}}\chi'_{i\dot{w}}(Z'_{q} + m') + M'_{\delta_{e}}\chi'_{w}Z'_{\dot{q}} + Z'_{\delta_{e}}M'_{i\dot{w}}\chi'_{\dot{q}} \\ &+ Z'_{\delta_{e}}M'_{i\dot{w}}\chi'_{\dot{q}} + M'_{\delta_{e}}(m' - Z'_{i\dot{w}})\chi'_{q} - M'_{\delta_{e}}Z'_{i\dot{w}}\chi'_{\dot{q}} \\ &- Z'_{\delta_{e}}\chi'_{i\dot{w}}M'_{q} + Z'_{\delta_{e}}\chi'_{i\dot{w}}(I'_{y} - M'_{\dot{q}}) \\ &- \chi'_{\delta_{e}}M'_{i\dot{w}}(Z'_{q} + m') - \chi'_{\delta_{e}}M'_{w}Z'_{\dot{q}} \\ &- \chi'_{\delta_{e}}M'_{i\dot{w}}(Z'_{q} + m') - \chi'_{\delta_{e}}M'_{w}Z'_{\dot{q}} \end{split}$$

$$C_{\mu} = -\chi'_{\delta_{e}}(m' - Z'_{iw})M'_{\theta} + \chi'_{\delta_{e}}Z'_{w}M'_{q} + M'_{\delta_{e}}\chi'_{iw}Z'_{\theta}$$

$$+ M'_{\delta_{e}}\chi'_{w}(Z'_{q} + m') + Z'_{\delta_{e}}M'_{iw}\chi'_{\theta} + Z'_{\delta_{e}}M'_{w}\chi'_{q}$$

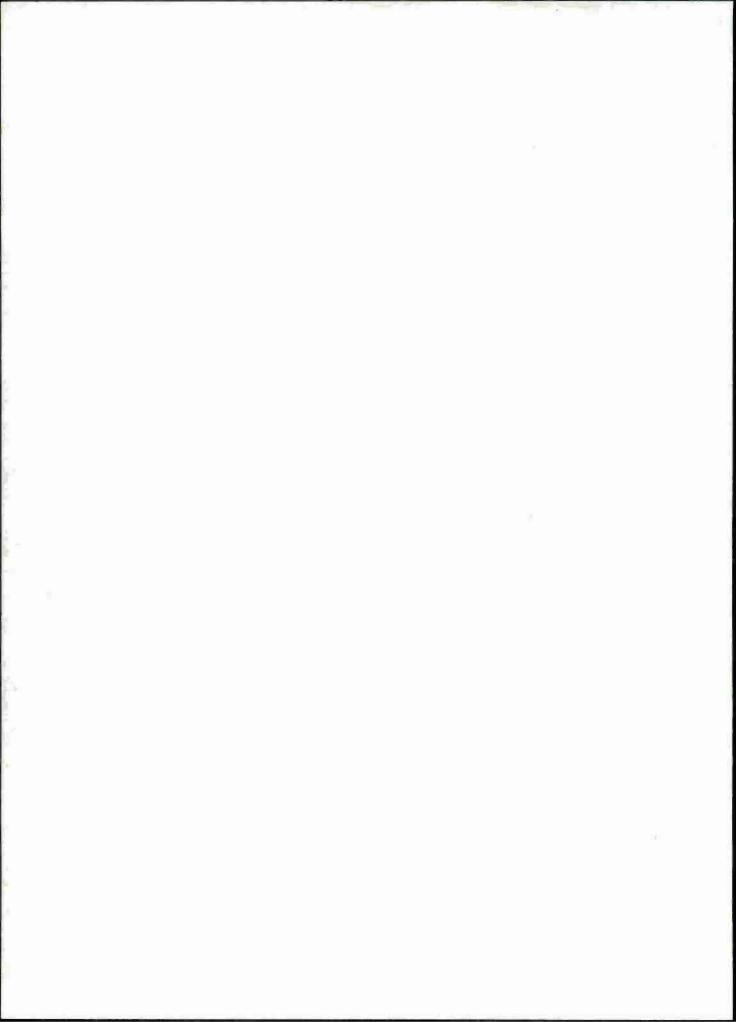
$$+ M'_{\delta_{e}}(m' - Z'_{iw})\chi'_{\theta} - M'_{\delta_{e}}Z'_{w}\chi'_{q} - Z'_{\delta_{e}}\chi'_{iw}M'_{\theta}$$

$$- Z'_{\delta_{e}}\chi'_{w}M'_{q} - \chi'_{\delta_{e}}M'_{iw}Z'_{\theta} - \chi'_{\delta_{e}}M'_{w}(Z'_{q} + m') .$$

$$D_{\mu} = \chi_{\delta_{e}}' Z_{w}' M_{\phi}' + M_{\delta_{e}}' \chi_{w}' Z_{\phi}' + Z_{\delta_{e}}' M_{w}' \chi_{\phi}'$$
$$-M_{\delta_{e}}' Z_{w}' \chi_{\phi}' - Z_{\delta_{e}}' \chi_{w}' M_{\phi}' - \chi_{\delta_{e}}' M_{w}' Z_{\phi}'.$$

## APPENDIX C

LONGITUDINAL CONTROL SYSTEM ANALYSIS
PROGRAM - CARD LIST



```
C-3
```

```
SSET EREFFORM SERVED RESET LIST
                                                                            000000066
FILE 1=LOCSAP/DATA-UNIT=DISK-SAVE=30.BLOCKING=3.RECURD=10
                                                                            000000016
     3=D/S,UNIT=REMOTE, LOCK, RECORD=9
FILF
                                                                            12000000
FILE 4=LOCSAP/TIMEPLT,UNIT=DISK.SAVE=30.LOCK,AREA=200.
                                                                            00000036
      ALOCKING=3. RECORD=10
                                                                            00000046
C -
      ******** SORCE FILE IS INCCAP/JANO275 ******
                                                                            00000056
      REAL KT, KIORG, KTEIN, KZD, KZDORG, KZDEIN, KZ, KZORG, KZEIN
                                                                            000000060
      REAL KINNEG, KID, KIDEIN, NVAL
                                                                            00000016
      DIMENSTON RIDE1(7) + RTE2(7) + RZDE3(7) + RZZZO(8) + OZDE3(6) + OTDE1(6)
                                                                            00000000
      DIMENSIUN NTED(K)
                                                                            00000090
      DIMENSION OTDF1R(6), OTDF11(6), OTE2R(6), OTE2I(6), OZDE3H(6),
                                                                            00000100
                                                                            00000110
      07DF31(6), TITLE(11)
      RADIAN = 180/(4*AIAN(1))
                                                                            00000126
                                                                            00000130
      READ(1,4000) (TITLE(1),1=1,11)
 4000 FURNAT(1146)
                                                                            00000146
      WRITE(3,4001) (TITLE(1),1=1,11)
                                                                            00000150
 4001 FORMAT (//, 11AK)
                                                                            00000160
      WRITE(3,3101)
                                                                            00000176
 3101 FORMAT(//, "PRINT STAR DERIV, nIMRIS, TECPRI...")
                                                                            00000186
      READ (3,/,FND=90)NVAL,IDIMRTS.ITECPHT; ISDPRNT=NVAL
                                                                            00000190
                                                                            00000200
      REAL IY, LB, M, MU, MW . MTH, MQ, MID, MWD, MQD, MX, M7, MDELT, MTHISG
                                                                            00000210
      READ(1)/PEND=09) UPLB, ICARIF
  104 FORMAT(////)
                                                                            000000220
  301 READ(1,/,END=99)XU,ZU,MU,XW,ZW,MW,XTHUSQ,ZTHUSQ,MTHUSQ,XQ,ZQ,MQ,
                                                                            00000236
       XUD, ZUD, MUD, XWD, ZWD, MWD, XQD, ZQD, MQD, XX, ZX, MX, XZ, Z/, MZ, XDELT,
                                                                            00000246
       ZDELT, MDELT, M, TY; XTH=XTHUSQ/(U*U); ZTH=ZTHUSQ/(U*U)
                                                                            00000250
      MTH=MTHUSQ/(U+U)
                                                                            00000200
   311 IF (ISDPHNT . EQ. 0) GO TO 351
                                                                            00000270
      WRITE (3,321)
                                                                            00000280
   321 FORMAT(//20X, "S N A M E NON-DIMENSIONAL")
                                                                            00000570
      WRITE (3.331)
                                                                            00000300
   331 FORMAT(16X, MLONGITUDINAL STARILITY DERIVATIVES M//)
                                                                            00000310
      WRITE(3,341)XU,7U,MU,XW,ZW,MW.XTH,7TH,MTH,XQ.ZQ,MQ,XUD,ZUD,MUD,XWCOUOU032U
      >ZWD, MWD, XQD, ZQD, MQD, XX, ZX, MX, XZ, ZZ, MZ, XDELT, ZDFLT, MDFLT, M, IY, U, LB000U033U
   341 FORMAT(1X, "XII =", F12.5.4X."ZU =", F12.5, 4X, "MU =", E12.5/, 00000340
                       =",E12.5,4x,"ZW =",E12.5,4X,"MW =",E12.5/, 0000035U
             1 X > " X W
             1x, "XTH = ", F12.5, 4x, "ZTH = ", F12.5, 4x, "MTH = ", F12.5/, 00000360
                       =",E12.5,4x,"ZQ =",E12.5,4x,"MQ =",E12.5/, 000003/U
             1 X , " X ()
```

```
C-4
```

```
1X, "XUD
                        =" , E12 . 5 . 4 X , " ZUD
                                             =" . E12 . 5 . 4 X . "MUD
                                                                  =",E12.5/, 00000380
                                                                  =",E12.5/, 00000390
                                             =",E12.5,4X,"MWD
              1X, "XWD
                        =",E12.5,4X,"ZWD
                                                                  =",E12.5/, 0000040U
                                             =",E12.5,4X,"MQD
              1X, "XQD
                        =" , E12.5 , 4 X , " ZQD
                                             =",E12.5,4X,"MX
                        =" , E12 . 5 , 4 X , " Z X
                                                                  =",E12.5/, 000U041U
              1 X . " X X
                                             =",E12.5,4X,"MZ
                                                                 =",E12.5/, 00000420
             1 X , " X Z
                        = " , E12 , 5 , 4 X , M ZZ
             1X, "XDELT =", E12.5, 4X, "ZDELT =", E12.5, 4X, "MDELT =", E12.5// 00000430
            ,9X, "M
                        =",E12.5,8X,"IY
                                             =",E12.5//,
                                                                              00000440
                                                                              00000450
                        =",E12.5,8x,"LB
                                             =",E12,5//)
              9X . "110
                                                                              00000460
  351 CONTINUE
  110 FORMAT(/,"J=",10X,"ECONV=",F12.5)
                                                                              00000470
        DIMENSION DS(A), XS(B), ZS(A), TS(B), ROOTR(B), ROOTI(B), ECONV(B)
                                                                              00000480
      CONTINUE
                                                                              00000490
      U=0U
                                                                              00000500
      N=6
                                                                              00000510
                                                                              00000520
      NP1=N+1
      Z0=ZQ+M
                                                                              00000530
                                                                              00000540
      DCST=LB
      IF (ICABLE.EQ. n) DCST=UO
                                                                              00000550
                                                                              00000560
C-
      NON-DIMENSIONAL D(S) COEFFICIENTS FOR TOWED VEHICLES
C -
                                                                              00000570
                                                                              00000584
C=
      DS(7)=(M-XUD)*(M-ZHD)*(IY-MQD)-XWD*ZQU*MUD
                                                                              00000590
      -XQD+ZUD+MWD-(M-XUD)+ZQD+MWD
                                                                              00000600
                                                                              00000610
      =XWD*ZUD*(IY=MQD)=XQD*(M=ZWD)*MUD
      DS(6)==XU*(M=ZWD)*(IY-MQD)=(M=XUD)*ZW*(IY-MQD)=(M-XUD)*(M-ZWD)*MQ 00000620
      -XW*ZQD*MUD-XWD*ZQ*MUD-XWD*ZQD*MU
                                                                              00000630
      -XQ*ZUD*MWD-XQD*ZU*MWD-XQD*ZUD*MW
                                                                              00000640
      +XU+ZQD+MWD=(M=XUD)+ZQ+MWD=(M=XUD)+ZQD+MW
                                                                              00000650
      -XW+ZUD+(IY-MQD)-XWD+ZU+(IY-MQD)+XWD+ZUD+MQ
                                                                              00000660
      "XQ+(M=ZWD)+MUD+XQD+ZW+MUD=XQD+(M=ZWD)+MU
                                                                              00000670
      DS(5)==XX*(M=ZWn)*(IY=MQD)+XU*ZW*(IY=MQD)=(M=XUD)*ZZ*(IY=MQD)
                                                                              00000680
      +XU + MQ + ( M = ZWD ) + ( M = XUD ) + ZW + MQ = ( M = XUD ) + ( M = ZWD ) + MTH
                                                                              00000690
      -xZ*ZQD*MUD-XW*7Q*MUD-XWD*7TH*MUD-XW*MU*ZQD=XWD*ZQ*MU-XWD*ZQD*MX
                                                                              00000700
      -XTH*ZUD*MWD-XQ*ZU*MWD-XQD*ZX*MWD-XQ*ZUD*MW-XQD*ZU*MW-XQD*ZUD*MZ
                                                                              00000710
      +XX+ZQD+MWD+XU+ZQ+MWD=(M=XUD)+ZTH+MWD+XU+ZQD+MW
                                                                              00000720
                                                                              00000730
      -(M-XUD)*ZQ*MW-(M-XUD)*ZQD*MZ
      =XZ*ZUD*(IY=MQD)=XW*ZU*(IY=MQD)=XWD*ZX*(IY=MQD)
                                                                              00000740
      +XW*ZUD*MQ+XWD*ZU*MQ+XWD*ZUD*MTH
                                                                              00000750
```

```
00000760
  -xTH+(M-ZWD)+MUn+xQ+?w+MUD+xQn+ZZ+MUD-XQ+(M-ZWD)+PU
                                                                            000007/6
  +XQD+ZW+MU=XQD+(M=ZWD)+MX
  DS(4)=XX+ZW+(TY=MOD)+XU+ZZ+(TY=MOD)+XX+(M=ZWD)+MO=XU+ZW+M6
                                                                            00000786
                                                                            00000796
  +(M=XU[))*Z7*MQ+XU*(M=/WD)*MTH+(M=XUD)*ZW*MTH
                                                                            000000806
  -XZ*ZQ*MUU-X**ZTH*MUD-XZ*Z0D***U-X**ZQ*MU
  = X W D + Z T H + M U = X W + 7 Q D + M X = X W D + 7 Q + M X
                                                                            00000816
                                                                            00000826
  -XTH+ZU*MWN-XQ*7X*MWN-XTH*7110*MW-XQ*ZU*MW
  -xqn+Zx+Mw-xg+Z110+MZ-xqn+711+M7
                                                                            00000830
  +XX+ZQ+MWD+XU+ZTH+MWD+XX+ZQD+MW+XU+ZQ+MW=(M=XUD)+ZTH+MW-
                                                                            00000840
                                                                            00000856
  + X U + Z Q D + M Z = ( M = X II D ) + Z Q + M Z
                                                                            00000866
  -XZ*ZU*(IY-MQD)-XW*ZX*(IY-MQD)+XZ*ZUD*MQ+XW*ZU*MQ
                                                                            00000876
  +XWD+7X+MQ+XW+Z11D+MTH+XWD+711+MTH
                                                                            000000880
  + X T H + Z W + M U D + X Q + 7 Z + M U D = X T H + ( M = Z W D ) + M U + X Q + Z W + M U
                                                                            000000896
  +xQD+77*M(I=XQ*(u=ZWD)*MX+xQD*7W*MX
                                                                            00000900
  DS(3)=XX+/Z+(TY=MQD)-XX+ZW+MQ=XU+ZZ+MQ+XX+(M-ZWD)+MIH
                                                                            00000910
  = XU + ZW + HTH + (M = XII) ) + ZZ + MTH
  -XZ*7TH*MUD-XZ*7Q*MU-XW*/TH*MI-XZ*7QD*MX
                                                                            00000920
  = X W + 7 Q + M X = X W () + Z T H + M X
                                                                            00000930
  "XTH*ZX*MWD"XTH*ZU*MW"XQ*ZY*MW"XTH*ZUD*MZ
                                                                            00000946
                                                                            00000950
  -xQ*7U*MZ-XQI)*Zx*MZ
                                                                            00000966
  +XX+7TH+MWD+XX+70+MW+XU+7TH+MW+XX+7QD+M7
                                                                            00000910
  +XU+ZQ+MZ=(M=XUn)+ZTH+MZ
  -XZ*ZX*(IY-MQD)+XZ*ZU*HQ+XW*ZX*MQ+XZ*ZUD*MTH
                                                                            00000980
  +XW+ZU*MTH+XWD*7X*MTH
                                                                            00000990
  +XTH*7Z*MUD+XTH*7W*MU+XQ*77*MH=XTH*(M=ZWD)*MX
                                                                            00001000
                                                                            00001016
  +XQ+ZW+MX+XQD+Z7+MX
                                                                            00001020
  DS(2)=+XX+7Z+MQ-XX+ZN+MTH-XII+7Z+MTH
                                                                            00001030
  *XZ*ZTH*MU=X/*ZO*MX*Xn*ZTH*MX
                                                                            00001046
  -xTH+ZX+MW-XTH+7U+MZ-xQ+ZX+MZ
                                                                            00001056
  +XX*ZTH*MW+XX*ZO*MZ+XU*ZTH*MZ
                                                                            00001060
  + X Z * Z X * M Q + X Z * Z U * M T H + X N * Z X * M T H
                                                                            000010/6
  +xTH*27*MU+XTH*7W*MX+xQ*27*MX
  DS(1)==XX+7/+MTH=XZ+ZTH+MX=XTH+ZX+MZ
                                                                            00001086
                                                                            00001096.
  +XX+2TH+M2+X2+2X+MTH+XTH+77+MX
                                                                            00001100
  WRITE (3,3)
3 FURMAT (//,20x, **** DENOMINATUR DS(J) ****)
                                                                            00001110
                                                                            00001120
  nn 4 J=1, NP1
                                                                            00001136
```

4 IF (DS(J).NF.O.O) GU TO 14

```
WRITE (3,5)
                                                                         00001140
    5 FORMAT (/,16X,"***** DS(J) CHEFFICIENTS ALL ZERO ******)
                                                                         00001150
                                                                         00001160
      GO TO 20
                                                                         00001170
    8 FORMAT (//(12X_{PM}J = \%_{I}3_{P}10X_{PM}DS = \%_{I}E20.12))
  11 FORMAT (/,15x,"J = ",13,10x,"FCONV = ",E15.8)
                                                                         00001180
   13 FORMAT (//(1X,"J = ",13,9X,"ROOTR = ",E12,5,9X,"ROOTI = ",E12,5)) 00001190
                                                                         00001200
C =
      DIMENSIONALIZE THE COEFFICIENTS OF THE DENOMINATOR TRANSFER
                                                                         00001210
C-
                                                                         00001220
C-
      FUNCTION
                                                                         00001230
C=
                                                                         00001240
   14 DO 15 I=1,NP1
   15 DS(I)=DS(I)*((LR/U)**(I=1))
                                                                         00001250
      IF (ITFCPRT.NE.1) GO TO 17
                                                                         00001260
      WRITE (3,16)
                                                                         00001270
   16 FORMAT (//,22x, "DIMENSIONAL CREFFICIENTS")
                                                                         00001280
                                                                         00001290
      WRITE (3,8) ((J,DS(J)),J=1,NP1)
   17 CALL PRNBM (N,DS, ROOTR, ROOTI, FCONV)
                                                                         00001300
                                                                         00001316
      00 18 J=1,N
   18 IF (ECONV(J).GT..5E-09) WRITE(3,11) J,ECONV(J)
                                                                         00001320
                                                                         00001330
      IF (IDIMRTS.EQ.O) GO TO 1
                                                                         00001340
      WRITE (3,19)
   19 FORMAT (//,25X, "DIMENSIONAL ROOTS")
                                                                         00001350
      WRITE (3,13) ((J,ROOTR(J),ROOTI(J)),J=1,N)
                                                                         00001360
                                                                         00001370
   20 WRITE (3,21)
                                                                         00001380
   21 FORMAT (//)
    1 N=4
                                                                         00001390
                                                                         00001400
      NP1=N+1
                                                                         00001410
C-
      NON-DIMENSIONAL X(S) COEFFICIENTS FOR TOWED VEHICLES
C-
                                                                         00001420
                                                                         00001430
C-
      XS(5)=(M-ZWD)*(TY-MQD)*XDFLT+XWD*ZQD*MDELT+XQD*MWD*ZDELT
                                                                         00001440
                                                                         00001450
      -ZQD+MWD+XDELT+XWD*(IY-MQD)+ZDELT+XQD*(M-ZWD)*MDELT
      XS(4)==ZW*(TY=MQD)*XDELT=(M=ZWD)*M0*XDELT
                                                                         00001460
      +XW+ZQD+MDELT+XWD+ZQ+MDELT
                                                                         000014/0
      +XQ*MWD*ZDELT+XQD*MW*ZDELT
                                                                         00001480
                                                                         00001490
      =ZQ+MWD+XDELT=ZQD+MW+XDELT
      +XW*(IY=MQD)*ZDFLT=XWD*MQ*ZDELT
                                                                         00001500
      +XQ+(M=ZWD)+MDELT-XQD+ZW+MDELT
                                                                         00001510
```

```
XS(3)==7Z*(TY=MOD)*XDELT+ZW*MO*XDFIT=(M=ZWD)*MTH*XDELT
                                                                           00001526
      +XZ+ZQD+MUFLT+XW+ZQ+MUFLT+XWD+ZTH+MDELT
                                                                           00001536
      +XTH+MWD+ZDFLT+VQ+MW+ZDELT+XQD+M7+7DELT
                                                                           00001546
      "ZTH*MUD*XDFLT"70*MW*XDELT=190*M1*XDELT
                                                                           00001556
      +X7*(1Y=MQD)*/DFLT=XW*MQ*/DFLT=XWD*MTH*/DELT
                                                                           00001566
      +XTH*(M=ZWD)*MDFLT=XQ+ZW+MDFLT=XQD*ZZ*MDELT
                                                                           00001576
      XS(2)=ZZ*MQ*XDELT+ZW*MTH*XDFLT+X7*7Q*MDELT+XW*ZTH*MDELT
                                                                           00001586
      +XTH*MW*/DFIT+XO*MZ*7()ELT=7TH*MW*XDELT=ZQ*MZ*XDFLT
                                                                           00001596
      =X7 *MQ * ZDEL T = XW * MTH * ZDEL T = X TH * ZW * WDEL T = XQ * ZZ * MDFL T
                                                                           00001600
      XS(1)=ZZ*MTH*XDFLT+XZ*ZTH*MDE1 T+XTH*MZ*ZDELT
                                                                           00001610
      -ZTH*MZ*XUFLT-X7*MTH*ZDELT=XTH*ZZ*MDELT
                                                                           00001620
      WRITE (3,2122)
                                                                           00001630
 2122 FORMAT (//*/3X*"**** X NUMERATOR ****")
                                                                           00001646
      DO 25 J=1, NP1
                                                                           00001656
   25 IF (XS(J). NE. n. n) GU TO 31
                                                                           00001660
      WRITE (3,26)
                                                                           00001670
   26 FORMAT (/, 13X, "+ * * * XS(J) CHEFFICIENTS ALL ZERU * * * * * * ")
                                                                           00001680
      GO TO 35
                                                                           00001690
   28 FURMAT (//(12X,"J = ", I3,10X,"XS = ", E20.12))
                                                                           00001706
C =
                                                                           00001716
C =
      DIMENSIONALIZE THE COEFFICIENTS OF THE X NUMERATOR TRANSFER
                                                                           00001726
C =
      FUNCTION
                                                                           00001730
C =
                                                                           00001746
   31 DO 32 I=1,NP1
                                                                           00001750
   32 XS([)=XS([)+DCST*((L8/U)**([=1))
                                                                           00001760
      IF (ITFCPRT.NE.1) GO TO 33
                                                                           00001770
      WRITE (3:16)
                                                                           00001780
      WHITE (3,28) ((1,xS(J)),J=1,NP1)
                                                                           00001796
   33 CALL PRNRM (N.XS. ROOTH, ROOTT, FCONV)
                                                                           00001800
      DO 34 T=1.N
                                                                           00001810
   34 IF (ECONV(J).GT..SE=09) WRITE(3,11) J.ECONV(J)
                                                                           00001820
      TECTDIMRTS. FQ. 05 GO TO 36
                                                                           00001830
      WRITE (3,19)
                                                                           00001840
      WRITE (3,13) ((J,ROOTK(J),ROOTI(J)),J=1,N)
                                                                           00001850
   35 WRITE (3,21)
                                                                           00001866
   36 N=4
                                                                           00001876
      NP1=N+1
                                                                           00001886
C =
                                                                           00001896
```

```
C-
       NON-DIMENSIONAL 7(S) COEFFICIENTS FOR TOWED VEHICLES
                                                                           00001900
 C -
                                                                           00001910
       7S(5)=(M=XUD)*(TY=MQD)*ZDFLT+7QD*MUD*XDFLT+XQD*ZUD*MDFLT
                                                                           00001920
       +(M=XUD) *ZQD*MDFLT+ZUD*(IY=MQn) *XDFLT=XQD*MUD*ZDELT
                                                                           00001930
       ZS(4) = = XU + (IY - MQD) + ZDELT - (M = XIID) + MQ + ZDELT
                                                                           00001940
       +ZQ*MUD*XDELT+ZQD*MU*XDELT
                                                                           00001950
       +XQ*ZUD*MDELT+XQD*ZU*MDELT=XU*ZQD*MDELT+(M=XIID)*ZQ*MDELT
                                                                           00001960
       +ZU*(IY=MQD) *XDFLT=ZUD*MQ*XDELT
                                                                           00001970
       =XQ*MUD*ZDELT=XQD*MU*ZDELT
                                                                           00001980
       ZS(3)==XX*(TY=MoD)*ZDELT+XU*Mo*ZDELT=(M=XUD)*MTH*ZDELT
                                                                           00001990
       +ZTH*MUD*XDELT+79*MU*XDELT+79n*MX*XDELT+XTH*7UD*MDELT
                                                                           00002000
       +XQ+ZU+MDELT+XQn+ZX+MDELT
                                                                           00002010
       =XX+7QD+MDELT-XII+ZQ+MDELT+(M-XUD)+ZTH+MDELT
                                                                           00002020
       +ZX+(IY-MQD)+XDFLT-ZU+MQ+XDFLT-ZUD+MTH+XDELT
                                                                           00002030
       -XTH+MUD+ZDELT-XQ+MU+ZDELT-XQD+MX+7DELT
                                                                           00002040
       ZS(2)=XX+MQ+ZDELT+XU+MTH+ZDFLT+ZTH+MU+XDELT+7Q+MX+XDELT
                                                                           00002050
       +XTH+ZU+MDELT+XQ+ZX+MDELT=XX+7Q+MDFLT=XU+ZTH+MDFLT
                                                                           00002066
       -ZX*MQ*XDELT-ZU*MTH*XDELT-XTH*MU*ZDELT-XQ*MX*ZDELT
                                                                           00002070
       ZS(1)=XX+MTH+ZDFLT+ZTH+MX+XDFLT+XTH+ZX+MDELT
                                                                           00002080
       -XX*ZTH*MDELT-ZX*MTH*XDELT-XTH*MX*7DELT
00 =
                                                                           00002090
       WRITE (3,350)
                                                                           00002100
   350 FORMAT (//,23X, ***** 2 NUMFRATOR *****)
                                                                           00002110
       DO 39 J=1, NP1
                                                                           00002126
    39 IF (ZS(J).NE.O.O) GU TO 45
                                                                           00002130
       WRITE (3,40)
                                                                           00002140
    40 FORMAT (/,12X,"+*** ZS(J) COFFFICTENTS ALL JERO *****
                                                                           00002150
       GO TO 49
                                                                           00002160
    42 FORMAT (//(12X, "J = ", 13, 10x, "ZS = ", E20, 12))
                                                                           00002170
 C-
                                                                           00002180
 C-
       DIMENSIONALIZE THE COEFFICIENTS OF THE Z NUMERATOR TRANSFER
                                                                           00002190
       FUNCTION
 C-
                                                                           00005500
                                                                           00002210
    45 DU 46 I=1,NP1
                                                                           00005550
    46 ZS(I)=ZS(I)*DCST*((LB/U)**(I=1))
                                                                           00002230
       IF (ITFCPRT.NE.1) GU TU 47
                                                                           00002240
       WRITE (3,16)
                                                                           00002256
       WRITE (3,42) ((J,ZS(J)),J=1,NP1)
                                                                           00002266
    47 CALL PRNBM (N.ZS, ROOTE, ROOTE, FCONV)
                                                                           00002270
```

```
00 48 J=1 N
                                                                           00005596
   48 IF (ECONV(J).GT...5E=79) WRITE(3,11) J,ECUNV(J)
                                                                           000012240
      IF (IDIMRIS.FR. 0) GO TU 50
                                                                           00002306
      WRITE (3,19)
                                                                           00002316
      WRITE (3,13) ((1,RNOTK(J),RNOTI(J)),J=1,N)
                                                                           000012320
   49 WRITE (3,21)
                                                                           000002330
   50 N=4
                                                                           00002346
                                                                           00002356
      NP1=N+1
C -
                                                                           00002366
      NON-DIMENSIONAL T(S) COEFFICIENTS FOR TOWED VEHICLES
C -
                                                                           000012376
C =
                                                                           00002380
      TS(5)=(M"XUD)+(M"ZWD)+MDELT+XWD+MUD+ZDFLT+ZUD+MWD+XDELT
                                                                           00002396
      +(M=XUD)+MWD+7DFLT=XwU+ZUD+MDFLT+(M=ZwD)+MUD+XDFL1
                                                                           00002406
      TS(4)==XU+(M=7WD)+MDELT=(M-XUD)+ZW+MDELT
                                                                           00002416
      +XW±MUD±ZDFLT+XWD±MU±ZDFLT+ZU±MWD±XDFLT+ZUU±MW±XDELT
                                                                           00002426
      -XU+MWD+ZDELT+(M-XUD)+MW+7DFLT-XW+7UD+MDFLT-XWD+ZU+MDELT
                                                                           00002430
      - ZW + MUD + XDELT+ (H = ZWD) + MU + XDFLT
                                                                           00002446
      TS(3)=-XX*(M-7WP)*MDFLT+XU*7W*MDELT-(M-XUD)*72*MDELT
                                                                           00002450
      +X7*MUD*ZDFLT+XW*MU*7DELT+XWD*MX*7DELT
                                                                           00002460
      +ZX*MWD*XDELT+ZII*MW*XDELT+7IID*MZ*XDELT
                                                                           00002476
      =XX*MWD*ZDFLT=XII*MW*ZDELT+(M=XUD)*MZ*ZDFLT
                                                                           00002480
      -XZ*7UD*MDELT=XW*ZU*MDELT=XWD*ZX*MDELT
                                                                           00002490
      "77*MUD*XUELT"7W*MU*XDELT+(M"7WD)*MX*XDELT
                                                                           00002500
      TS(2)=XX+ZW+MDELT+XU+ZZ+MDFLT+XZ+MII+ZDELT+XW+MX+ZDELT
                                                                           00002516
      +ZX +MW + XDEL T + ZU + MZ + XDEL T = XX + MW + ZDFL T = XU + MZ + ZDEL T
                                                                           00002520
                                                                           00002530
      -XZ*ZU*MDELT-XW*ZX*MDELT-7Z*MII*XDELT-ZW*MX*XDELT
                                                                           00002540
      TS(1)=XX*ZZ*MDE| T+XZ*MX*ZDF| T+ZX*MZ*XDELT
      -XX+MZ+ZDELT-XZ+7X+MDELT-77+MX+XDFLT
                                                                           00002550
                                                                           00002560
      WRITE (3,52)
   52 FORMAT (//+23X+"++++ 1 NUMFRATOR ++++")
                                                                           00002570
                                                                           00002586
      DO 53 J=1, NP1
   53 IF (TS(J), NF. 0, n) GD 10 59
                                                                           00002590
                                                                           00002600
      WRITE (3,54)
   54 FORMAT (/,13x,"***** TS(J) CHEFFICIENTS ALL ZERO ******)
                                                                           00002610
                                                                           00002620
      GO TO 63
   56 FURMAT (//(12x, mJ = ", 13, 10x, mTS = ", E20.12))
                                                                           00002636
C -
                                                                           00002640
      DIMENSIONALIZE THE COEFFICIENTS OF THE T NUMERATOR TRANSFER
C -
                                                                           00002650
```

C-		FUNCTION	00002660
	50	DO 60 I=1, NP1	00002680
		TS(I)=TS(I)*((LR/U)**(I=1))	00002696
		IF (ITFCPRT.NE.1) GO TO 61	00002700
		WRITE (3,16)	00002710
		WRITE (3,56) ((J,TS(J)),J=1,NP1)	00002720
	61	CALL PRNBM (N.TS. ROOTR, ROOTI, FCONV)	00002730
	0 (	DO 62 I=1,N	00002740
	62	IF (ECONV(J).GT5E=09) WRITE(3,11) J.ECONV(J)	00002750
		IF(IDIMRTS.EQ.O) GO TO 63	00002760
		WRITE (3/19)	00002770
		WRITE (3,13)((J.ROOTR(J),ROOTY(J)),J=1,N)	00002780
	63	CONTINUE	00002790
C =			00002800
C-			00002810
C-			00002820
		QTDE1(6)=TS(5)	00002830
		OTDE1(5)=TS(4)	00002840
		OTDE1(4)=TS(3)	00002850
		OTOE1(3)=TS(2)	00002860
		OTDE1(2)=TS(1)	00002870
		OTDE1(1)=0.0	00002880
		N=53N10=N	00002890
		CALL PRNBM(N,OTDE1,OTDE1R,OTDF1I,ECONV)	00002900
		WRITE(3,3201)(OTDE1R(J10),OTDF1I(J10),J10=1,N)	00002910
3	201	FORMAT(/, "ZEROS OF TD/E1", /, 4(F9.4, F9.4))	00002920
		N=4; N12=N	00002930
		DO 2000 I1=1.5	00002940
		OTE2(I1)=TS(I1)	00002950
2	000	CONTINUE	00002960
		CALL PRNBM(N, OTF2, OTE2R, OTF2I, ECONV)	00002970
		WRITE(3,3202)(OTE2R(J12),OTE2T(J12),J12=1,N)	00002980
320	15	FURMAT(/, MZEROS OF T/E2M, /, 4(F9.4, F9.4))	00002990
		OZDE3(6)=ZS(5)	00003000
		OZDE3(5)=ZS(4)=TS(5)+U0	00003010
		0ZDF3(4)=ZS(3)=TS(4)+U0	00003020
		DZDE3(3)=ZS(2)=TS(3)*U0	00003030

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	٦	4	9
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1	h		B
í	L		ı

	OZDE3(2)=ZS(1)=TS(2)*UU	00003040
	OZDF3(1)==TS(1)+U()	00003050
	N=5;N14=N	00003066
	CALL PRNAM(N. NZDE3, OZUE3R, OZUF3I, ECUNV)	00003076
	WHITE(3,3203)(U7NE3H(J14),N7DF3I(J14),J14=1,N)	00003080
3203	FORMAT (/ "ZEROS OF ZD/E3 AND 7/ZU" , / , 4(F9.4) Fy.4))	00003090
2997	WRITE(3,2998)	00003100
2998	FORMAT ("ENTER KIDORG + UELKID + KIDFIN" + /)	00003116
	READ(3,/)KTDORG, DELKTU, KTDFIN	00003120
	IF (DFLKTD.EQ.D) GO TO 99	00003130
	NGAIN=(KIDFIN=KTDORG)/DELKTD+1	00003140
	KID=KIDURG	00003150
	00 3001 JD=1 NGAIN	00003160
	RIDF1(7)=US(7)	000031/0
	RTDE1(6)=DS(6)=KTD+TS(5)	00003186
•	RTOE1(5)=DS(5)=KTD+TS(4)	00003190
	RTDF1(4)=DS(4)= $\kappa$ TD*TS(3)	00003200
	RTDE1(3)=US(3)=KID*TS(2)	00003210
	RIDE1(2)=US(2)=KID*TS(1)	00003220
	RTDE1(1)=DS(1)	00003230
	N=6	00003246
	CALL PRNBM(N,RThei,ROOTE,ROOTE,ECONV)	00003256
	DD 3006 J=1.N	00003260
	IF(ECONV(J) .GT5E=09) WRITE (3:110) J.ECONV(J)	00003276
2007	CONTINUE	00003270
3006		
2000	- WRITF(3,3002)KTn	00003290
3002	FORMAT(FR.2)	00003300
2002	WRITE(3,3003) (ROOTR(J),ROOTI(J),J=1,N)	00003310
3003	FURMAT(4(F9.4,F0.4))	00003320
3001	KTD=KTD+DELKTD	00003330
	WRITE(3,3004)	00003340
3004	FORMAT (MDO YOU WANT TO CONTINUE KIN R. LOCUSM)	00003350
	READ(3./)NVAL	00003360
	IF (NVAL.E0.1) GO TU 2997	00003370
3016	WRITE (3,3005)	00003380
3005	FORMAT ("ENTER KTD")	00003390
	READ(3,/)KTD	00003400
3007	WRITE(3,3008)	00003410

```
3008 FORMAT ("ENTER KTORG, DELKT, KTF IN")
                                                                            00003420
                                                                            00003430
        READ(3,/)KTORG, NELKT, KTFIN
        IF (DELKT. EQ. 0) GO TO 99
                                                                            00003440
        NGAIN=(KTFIN=KTORG)/DELKT+1
                                                                            00003450
        KT=KTDRG
                                                                            00003460
        DO 3012 JD=1, NGAIN
                                                                            00003470
                                                                            00003480
        RTE2(7)=DS(7)
        RTE2(6)=DS(6)=KTD+TS(5)
                                                                            00003490
                                                                            00003500
        RTE2(5)=DS(5)=KTD+TS(4)+KT+TS(5)
        RTE2(4)=DS(4)=KTD*TS(3)+KT*TS(4)
                                                                            00003510
                                                                            00003520
        RTE2(3)=DS(3)=KTD*TS(2)+KT*TS(3)
                                                                            00003530
        RTE2(2)=DS(2)=KTD*TS(1)+KT*TS(2)
        RTE2(1)=DS(1)+KT+TS(1)
                                                                            00003540
                                                                            00003550
        N=6
        CALL PRNBM(N,RTF2,ROOTR,ROOTI,ECONV)
                                                                            00003560
                                                                            00003570
        DO 3009 J=1.N
        IF(ECONV(J) .GT. .5E=09) WRITE (3,110) J,ECONV(J)
                                                                            00003580
  3009 CONTINUE
                                                                            00003590
        WRITE(3,3010)KT.
P WRITE(3,3010)K

→ 3010 FORMAT(F8.2)
                                                                            00003600
                                                                            00003610
                                                                            00003620
        WRITE(3,3011)((RNOTR(J),RNNTI(J),J=1,N))
  3011 FORMAT(4(F9.4)F9.4))
                                                                            00003630
  3012 KT=KT+DELKT
                                                                            00003640
                                                                            00003650
        WRITE(3,3013)KTD
                                                                            00003660
  3013 FORMAT("DO YOU WANT NEW KTD, 0=NO, 1=ENT, 2=ENT&COMP, KTD NOW=", F8.2) 00003670
                                                                            00003680
        READ(3,/)NVAL
        IF (NVAL.EQ.1) GO TO 3016; TF (NVAL.EQ.2) GO TO 2997
                                                                            00003690
                                                                            00003700
        WRITE(3,3014)
  3014 FORMAT("DU YOU WANT TO CONTINUE KT R. LOCUS")
                                                                            00003710
                                                                            00003720
        READ(3,/)NVAL
                                                                            00003730
        IF (NVAL .EQ. 1) GO TO 3007
  3017 WRITE(3,3015)
                                                                            00003740
  3015 FORMAT ("ENTER KT")
                                                                            00003750
        READ(3,/)KT
                                                                            00003760
  3018 WRITE(3,3019)
                                                                            00003770
  3019 FORMAT ("ENTER KZDORG, DELK7D, KZDFIN")
                                                                            00003780
        READ(3)/)KZDORG, DELKZD, KZDFIN
                                                                            00003790
```

```
TECRELKID, FO.O) GU TO 99
                                                                         COUUSEUU
      NGAIN=(KZDFIN=K7DURG)/DFLK7D+1
                                                                         0000381L
      KZD=KZDORG
                                                                         000003826
      DO 3022 JU=1, NGAIN
                                                                         000003836
      RZDF3(7)=DS(7)
                                                                         00003846
      RZDE3(6)=US(6)=KTU+TS(5)+(K/U/RAUTAN)+/S(5)
                                                                         00003850
      RZDF3(5)=DS(5)=KT()*TS(4)+KT*TS(5)+(KZ)/RADIAN)*(ZS(4)=TS(5)*UU)
                                                                        00003860
      RZDE3(4)=DS(4)=kTD*TS(3)+kT*T*(4)+(k7D/RADIAN)*(2S(3)=T*(4)*UU)
                                                                        00003870
      RZDF3(3)=DS(3)=KTU*TS(2)+KT*TS(3)+(KZD/RADIAN)*(ZS(2)=TS(3)*UU)
                                                                        00003880
      RZDE3(2)=DS(2)=KID*TS(1)+KT*TS(2)+(KZD/RADIAN)*(ZS(1)=TS(2)*UU)
                                                                        000003890
      R7DF3(1)=DS(1)+KT*TS(1)+(K7D/RADIAN)*(=TS(1)+UD)
                                                                        00003906
      N=6
                                                                        00003916
      CALL PRNBM(N, RZDF3, KOCTR, RDDTT, ECONV)
                                                                        00003920
      DD 3020 J=1.N
                                                                        00003936
      IF (ECONV(J) .Gr. .5E=09) WHITE (3,110) J. ECONV(J)
                                                                        00003946
3020 CONTINUE #WRITE(3,3110)K70
                                                                        00003950
      WRITE (3,3021)((RONTR(J),ROUTT(J),J=1,N))
                                                                        00003960
3021 FORMAT (4(F9.4,F9.4))
                                                                        00003970
3022
     KZD=KZD+DELKZD
                                                                        00003980
      WRITE(3,3099)KIn
                                                                        00003990
3099 FURMAT("DU YOU WANT NEW KID, KID NOW =",F8.2)
                                                                        00004000
      READ(3,/)NVAL
                                                                        00004016
      IF (NVAL.EQ.1) GO TO 3016; [F (NVAL.EQ.2) GO TO 2997
                                                                        00004020
      WRITE(3, 3023)KT
                                                                        00004030
3023 FORMAT("DO YOU WANT NEW KT. KT NOW = # + F8.2)
                                                                        00004040
      READ (3,/)NVAL
                                                                        00004050
      IF (NVAL.EQ.1) GO TO 3017; TF (NVAL .EQ.2) GU TO 3007
                                                                        00004066
      WRITE(3,3103)
                                                                        00004070
3103 FORMAT("DO YOU WANT TO CONTINUE KID R. LOCUS")
                                                                        00004080
      READ(3,/)NVAL
                                                                        00004090
      IF (NVAL. EQ. 1) ON TO 3018
                                                                        00004100
3024 WRITE(3,3025)
                                                                        00004110
3025 FORMAT ("ENTER K7D")
                                                                        00004126
      READ(3)/)KZD
                                                                        00004136
     WRITE(3,3098)
3026
                                                                        00004140
3098 FORMAT ("FNTER KZORG, DELKZ, KZEIN")
                                                                        00004150
      READ(3,/)KZORG, DELKZ, KZETN
                                                                        00004160
      TE (DELKZ . EQ . 0) GO TO 99
                                                                        000041/0
```

```
NGAIN=(KZFIN=KZORG)/DELKZ+1
                                                                          00004180
      KZ=KZDRG
                                                                          00004190
      DO 3029 JD=1 NGAIN
                                                                          00004200
      RZZO(8)=DS(7)
                                                                          00004210
      RZZO(7)=DS(6)=KTD*TS(5)+KZD*Zs(5)
                                                                          00004220
      RZZO(6)=DS(5)=KTD+TS(4)+KT+TS(5)+KZD+(ZS(4)=TS(5)+U0)=K7+ZS(5)
                                                                          00004230
      RZZO(5) = DS(4) = KTD * TS(3) + KT * TS(4) + KZD * (ZS(3) = TS(4) * UD) = K7 * (ZS(4)
                                                                          00004240
                                                                          00004250
      =TS(5)*UD)
      RZZO(4)=DS(3)+KT*TS(3)+KZD*(ZS(2)=TS(3)*U0)=KZ*(ZS(3)=TS(4)*U0)
                                                                          00004260
     =KTD+TS(2)
                                                                          00004270
      RZZO(3)=DS(2)+KT*TS(2)+KZD*(ZS(1)+TS(2)*UD)=KZ*(ZS(2)=TS(3)*UD)
                                                                          00004280
        =KTD+TS(1)
                                                                          00004290
      RZZO(2) = DS(1) + KT * TS(1) = KZD * TS(1) * UD = KZ * (ZS(1) = TS(2) * UD)
                                                                          00004300
      RZZ_{0(1)} = KZ_{*}(=T_{S(1)}*U0)
                                                                          00004310
       N=7
                                                                          00004320
      CALL PRNBM(N, RZ70, ROOTR, ROOTI, ECONV)
                                                                          00004330
      DD 3027 J=1.N
                                                                          00004340
      IF (ECONV(J) .GT. .5E=09) WRITE (3,110) J.ECONV(J)
                                                                          00004350
3027
     CONTINUE JWRITF(3,3110)KZ
                                                                          00004360
       GAIN=KZ*ZS(5)/NS(5)
                                                                          00004370
       WRITE(3,3250)GAIN
                                                                          00004380
       FORMAT("GAIN =", F8.4)
3250
                                                                          00004390
      WRITE (3,3028)((ROOTR(J),ROOTT(J),J=1,N))
                                                                          00004400
3028 FORMAT (4(F9.4,F9.4))
                                                                          00004410
3029 KZ=KZ+DELKZ
                                                                          00004420
      WRITE(3,3099)KTn
                                                                          00004430
      READ(3,/)NVAL
                                                                          00004440
      IF (NVAL.EQ.1) GO TO 3016; IF (NVAL.EQ.2.) GO TO 2997
                                                                          00004450
      WRITE(3,3023)KT
                                                                          00004460
      READ(3º/)NVAL
                                                                          00004470
      IF (NVAL. EQ. 1) GO TO 3017; TF (NVAL . EQ. 2) GO TO 3007
                                                                          00004480
      WRITE(3,3032)KZD
                                                                          00004490
3032 FORMAT("DO YOU HANT NEW K70, K70 NOW =", F8.4)
                                                                          00004500
      READ(3+/)NVAL
                                                                          00004510
      IF (NVAL .EQ.1) GO TO 3024; IF(NVAL.EQ.2)GO TO 3018
                                                                          00004520
      WRITE(3,3033)
                                                                          00004530
3033 FORMAT ("DU YOU WANT TO CONTINUE KZ R. LOCUS")
                                                                          00004540
      READ (3)/)NVAL
```

00004550

```
00004566
      IF (NVAL. EQ. 1) GU TU 3026
                                                                             00004576
                                                                             00004580
      WRITE(3,9000)
                                                                             00004596
 9000 FORMAT("DI) YOU WANT A TIMEPITA)
                                                                             00004606
      READ(3,/)NVAL
                                                                             00004616
      TF(NVAL.EQ.O) GO TO 99
                                                                             00004620
                                                                             00004636
C=
                                                                             00004646
      WRITE(4,4000) (TITLE(1), [=1,11)
                                                                             00004656
C=
                                                                             00004660
      STANDARD TEST VALUES USED FOR THESE TIMEPLIS
C -
                                                                             000046/6
      IF=1
                                                                             00004680
      TDEL=0.1
                                                                             00004690
      TMAX=20.
                                                                             00004706
      RIIME=0
                                                                             00004716
      PTIME=10.
                                                                             00004724
      W=O
                                                                             00004736
      IPLOT=1
                                                                             00004746
      TWRITE = 0
                                                                             00004750
      WRITE(4,9003) IF, TDEL, IMAX, RTINE, PTIME, W, TPLOT, IWRITE
                                                                             00004760
 9003 FORMAT(11,1H,, F5.3,1H,, F8.3,1H,, F10.5,1H,, F10.5,1H,,
                                                                             00004770
                                                                             00004780
      F10.5, 1H,, T5, 1H,, [5,2H,*)
                                                                             00004790
   88 WRITE(3,9001)
 9001 FORMAT ("ENTER KTD, KT, KZD, KT, GAMP")
                                                                             00004800
                                                                             00004810
      READ (3,/)KTD,KT,KZD,KZ,GAMP
                                                                             00004820
      WRITE(3,9002)
 9002 FORMAT ("TIMEPLT FOR WHICH I COP;",
                                                                             00004836
                                                                             00004840
      " ENTER 1=1ST, 2=2ND, 3=3RD, 4=4TH")
                                                                             00004850
      READ (3./) NVAL
                                                                             00004860
      IF (NVAL. EQ. 2) Gn TO 9100
                                                                             000048/6
      IF (NVAL. EQ. 3) GO TO 9101
                                                                             00004886
      IF(NVAL, EQ. 4) Gn TD 9102
                                                                             00004890
      GAIN=GAMP * (TS(5)/US(7))
                                                                             00004906
      WRITE(4,9004) N10, GAIN
                                                                             00004910
 9004 FORMAT(11,1H,,F15,5,2H,+)
      WRITE(4,9005)((NTUE1R(II), NTUF1I(II)), II=1, N10)
                                                                             00004920
                                                                             00004936
 9005 FURMAT(4(F12.5,1H,),1H/)
```

```
GO TO 9103
                                                                         00004940
9100 GAIN=GAMP*(TS(5)/DS(7))
                                                                         00004950
     WRITE(4,9006)N12, GAIN
                                                                         00004960
9006 FORMAT(11:1H: F15.5:2H: +)
                                                                         00004970
     WRITE(4,9007)((nTE2R(12),nTF2T(12)),12=1,N12)
                                                                         00004980
9007 FORMAT(4(F12.5,1H,),1H/)
                                                                         00004990
     GD TO 9103
                                                                         00005000
9101 GAIN=GAMP*(ZS(5)/DS(7))
                                                                         00005010
     WRITE (4,9008) N1 a, GAIN
                                                                         00005020
9008 FORMAT(I1,1H,,F15,5,2H,*)
                                                                         00005030
     WRITE(4,9009)((DZDE3R(13),DZDF31(13)),13=1,N14)
                                                                         00005040
9009 FORMAT (4(F12.5,1H,),1H/)
                                                                         00005050
9103 RZDE3(7)=DS(7)
                                                                         00005060
     RZDE3(6)=DS(6)=kTD*TS(5)+k7D*7S(5)
                                                                         00005070
     RZDE3(5)=DS(5)=KTD*TS(4)+KT*Ts(5)+KZD*(ZS(4)=TS(5)*UO)
                                                                         00005080
     RZDE3(4)=DS(4)=KTD*TS(3)+KT*TS(4)+KZD*(ZS(3)=TS(4)*UD)
                                                                         00005090
     RZDE3(3)=DS(3)+KT*TS(3)+K7D*(7S(2)=TS(3)*UD)=KTD*TS(2)
                                                                         00005100
     RZDE3(2)=DS(2)+KT*TS(2)+KZD*(7S(1)=TS(2)*U0)=KTD*TS(1)
                                                                         00005110
         RZDE3(1)=DS(1)+KT*TS(1)=K7D*TS(1)*UD
                                                                         00005120
     NEA
                                                                         00005130
     CALL PRNBM(N, RZDE3, ROOTR, ROOT; ECONV)
                                                                         00005140
     00 9010 J=1.N
                                                                         00005150
     IF (ECONV(J) .GT. .5E-09) WRITE (3,110) J,ECONV(J)
                                                                         00005160
9010 CONTINUE
                                                                         00005170
     WRITE(4,9011)N
                                                                         00005180
9011 FORMAT(11,2H,+)
                                                                         00005190
     WRITE(4,9012)((ROOTR(J6),ROOTT(J6)),J6=1,N)
                                                                         00005200
9012 FORMAT (4(F12.5,1H,),1H/)
                                                                         00005210
     GO TO 77
                                                                         00005220
                                                                         00005230
9102 GAIN=GAMP*((-KZ+ZS(5))/DS(7))
                                                                         00005240
     WRITE(4,9013)N14, GAIN
                                                                         00005250
9013 FORMAT(J1,1H,,F15,5,2H,+)
                                                                         00005260
     WRITE(4,9014)((DZDE3R(J7),D7DF3I(J7)),J7=1,N14)
                                                                         00005270
9014 FORMAT(4(F12.4,1H,),1H/)
                                                                         00005280
     RZZO(8)=DS(7)
                                                                         00005290
     RZZO(7)=DS(6)=KTD*TS(5)+KZD*ZS(5)
                                                                         00005300
     RZZO(6)=DS(5)-KTD*TS(4)+KT*TS(5)+K7D*(ZS(4)-TS(5)*UD)-K7*ZS(5)
                                                                         00005310
```

```
C-17
```

```
RZZO(5)=DS(4)=KTD*TS(4)+KT*TS(4)+KZD*(ZS(3)=TS(4)*UU)=KZ*(ZS(4)
                                                                             00005320
       -TS(5) +UU)
                                                                             00005336
      R770(4) = DS(3) + KT + TS(3) + KZD + (ZS(2) = TS(3) + UU) = K/ + (/S(3) = TS(4) + UU)
                                                                             00005346
     -KID+TS(2)
                                                                             00005350
      RZZO(3) = DS(2) + KT * TS(2) + KZD * (ZS(1) * TS(2) * UU) * KZ * (ZS(2) = TS(3) * UU)
                                                                             00005366
        -KID+TS(1)
                                                                             00005376
      RZZO(2)=DS(1)+KT*TS(1)=K7D*TS(1)*UD=KZ*(ZS(1)=TS(2)*UD)
                                                                             00005380
      R/ZO(1) = = K/T * (= TS(1) * U(1))
                                                                             00005396
       N = 7
                                                                             00005400
      CALL PRNRM(N, RZ70, RONTR, RONTI, ECONV)
                                                                             00005416
      DO 9015 J=1.N
                                                                             00005426
      IF (ECONV(J) .GT. .SE-09) WRITE (3:110) J.ECONV(J)
                                                                             00005436
 9015 CONTINUE
                                                                             00005446
      WRITE (4,9016)N
                                                                             00005450
 9016 FORPAT(11,2H,+)
                                                                             00005460
      WRITE(4,9017)((ROUTR(J9),ROOTT(J9)),J9=1,N)
                                                                             00005410
 9017 FORMAT(4(F12.5,1H,),1H/)
                                                                             00005480
   77 WRITE(3,9018)
                                                                             00005490
 9018 FORMAT ("DU YOU WANT ANOTHER TIMEPIT")
                                                                             00005506
      READ(3,/)NVAL
                                                                             00005516
      IF (NVAL. FQ. 1) Gn TO AR
                                                                             00005526
   99 CONTINUE
                                                                             00005530
                                                                             00005546
0=
0 =
      NOW WRITE PROGRAM COST INFORMATION
                                                                             00005550
C =
                                                                             00005560
      IT1=TIME(2)/60.0; XM1=0.05*IT1
                                                                             00005576
      IT2=TIMF(3)/60.0; XM2=0.03+1T2
                                                                            00005580
      IT3=TIME(7)/60.0; XM3=0.01*TT3
                                                                            00005596
      XM4=XM1+XM2+XM3
                                                                            00005600
      WRITE(3,51) IT1, XM1, 112, XM2, IT3, XM3, XM4
                                                                            00005610
   51 FORMAT (/, PROCESSOR TIME = ", 15, " SEC", 5X, "&", F6.2,/
                                                                            00005624
      " I/O TIME = ",15," SFC",5X,"$",F6.2,/
                                                                            00005630
      " PRORATED TIME = ",15," SEC",5X,"8",F6.21/
                                                                            00005640
                                                                            00005650
      20x, "TOTAL COST ", "$", F6, 2)
      STOP; FND
                                                                            00005660
      SUBROUTINE PRNBM (N.A.U.V.FCUNV)
                                                                             000056/6
      DIMENSION A(8), H(8), V(8), FCONV(8), H(8), B(8), C(8)
                                                                            00005680
      ICOUNT=1
                                                                             00005690
```

```
EFIX=.5E=09
                                                                             00005700
       CONV=1.E-35
                                                                             00005710
       NC = N + 1
                                                                             00005720
C-
                                                                             00005730
C-
       SEND COEFFICIENTS TO REDUCED COEFFICIENT STORAGE
                                                                             00005740
C=
                                                                             00005750
       DO 1 I=1.NC
                                                                             00005760
       ECONV(I)=0.0
                                                                             00005770
     1 H(I)=A(I)
                                                                             00005780
C-
                                                                             00005790
C-
       INITIALIZE GUESSES AND SET REVERSAL INDICATOR NORMAL
                                                                             00005800
C
                                                                             00005810
       P=0.
                                                                             00005820
       0=0.0
                                                                             00005830
       R=0.
                                                                             00005840
       IREV=1
                                                                             00005850
C-
                                                                             00005860
C-
       SCALING TO BE DONE AT THIS POINT AND REMOVE ALL ZERO ROOTS
                                                                             00005870
C =
                                                                             00005880
     2 IF(H(NC)) 4,3,4
                                                                             00005890
     3 NC=NC=1
                                                                             00005900
       V(NC)=0.0
                                                                             00005910
      U(NC)=0.0
                                                                             00005920
       GD TD 2
                                                                             00005930
    4 IF(H(1)) 7,5,7
                                                                             00005940
    5 NC=NC-1
                                                                             00005950
       V(NC)=0.
                                                                             00005960
      U(NC)=0.
                                                                             00005970
      DO 6 I=1.NC
                                                                             00005980
    6 H(I)=H(I+1)
                                                                             00005990
      GO TO 4
                                                                             00006000
C-
                                                                             00006010
       TEST FOR VARIOUS DEGREES
                                                                             00006020
C-
C-
                                                                             00006030
    7 IF (ICOUNT.LT.2) GO TO 8
                                                                             00006040
      ECONV(ICOUNT-1)=E
                                                                             00006050
    8 ICOUNT = ICOUNT + 1
                                                                             00006060
    9 IF(NC=1) 10,50,10
                                                                             00006070
```

```
10 TF(NC=2) 12,11,12
                                                                             U8030000
   11 R==H(1)/H(2)
                                                                             00006090
      GO TO 37
                                                                             00006106
   12 TE(NC=3) 10.13.14
                                                                             00006116
   13 P=H(2)/H(3)
                                                                             00006126
      Q=H(1)/H(3)
                                                                             00006130
      Gn Tn 42
                                                                             00006146
C =
                                                                             00006154
      TEST TO REVERSE CHEFFICIENTS AND DO SU IF TEST SUCCEEDS
C =
                                                                             00006160
0
                                                                             00006176
   14 IF(ABS(H(NC=1)/H(NC))=ABS(H(2)/H(1))) 15,21,21
                                                                             00006180
   15 TREV==TREV
                                                                             00006190
      M=NC/2
                                                                             00006200
      DO 16 I=1.M
                                                                             00006216
      NL = NC + 1 = I
                                                                             00006220
      F=H(NL)
                                                                             00006230
      H(NL)=H(I)
                                                                             00006240
   16 H(T)=F
                                                                             00006250
      TF(Q) 18,17,18
                                                                             00006260
   17 P=0.
                                                                             00006210
      GD TO 19
                                                                             00006286
   18 P=P/Q
                                                                             00006290
      9=1./9
                                                                             00006300
   19 IF(R) 20,21,20
                                                                             00006310
   20 R=1./R
                                                                             00006320
0-
                                                                             00006330
C -
      NEWTON, CALCULATE F(R) AND TEST FOR ROOT
                                                                             00006340
C =
                                                                             00006350
   21 E=FFTX
                                                                             00006360
      R(NC)=H(NC)
                                                                             000063/6
      C(NC) = H(NC)
                                                                             00006380
      R(NC+1)=0.
                                                                             00006396
      C(NC+1)=0.
                                                                             00006406
      NP=NC-1
                                                                             00006410
   22 DO 35 J=1,1000
                                                                             000006424
      DU 23 I1=1,NP
                                                                             00006436
      I=NC-11
                                                                             00006440
      B(I) = H(I) + R * B(I + 1)
                                                                             00006450
```

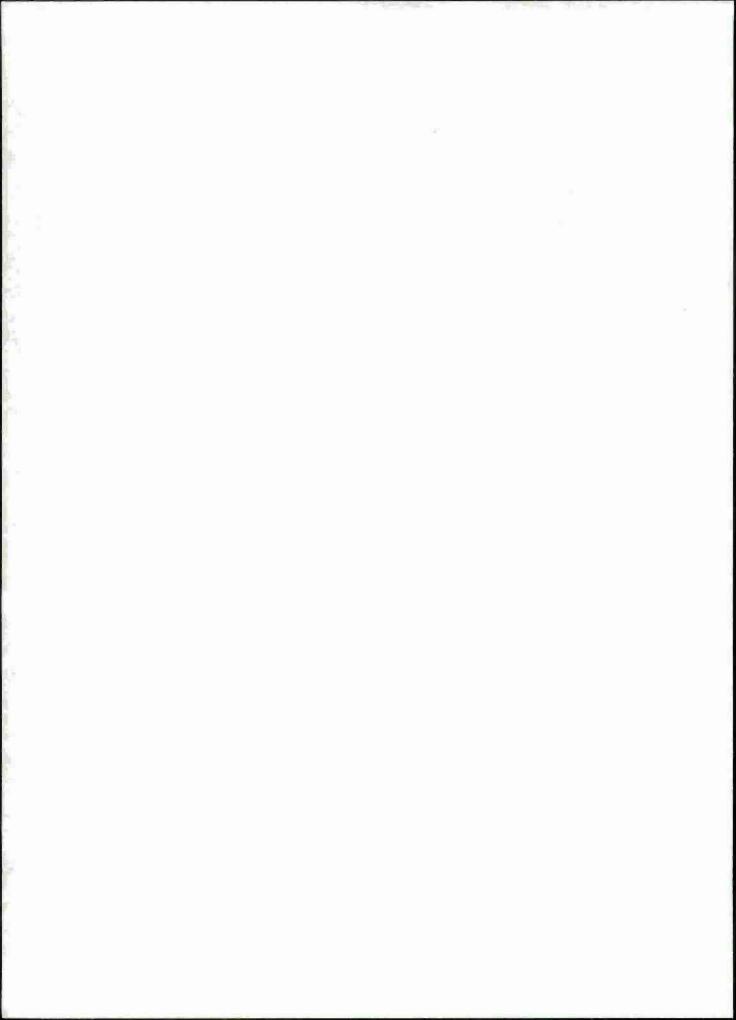
		23	C(I)=B(I)+R*C(I+1)	00006460
			IF(ABS(B(1)/H(1))=E) 37,37,24	00006470
		24	IF(C(2)) 26,25,26	00006480
		25	R=R+1.	00006490
			GO TO 27	00006500
		26	R=R=B(1)/C(2)	00006510
	C			00006520
	C-		MAKE A BAIRSTOW REDUCTION AND CORRECT	00006530
	C-			00006540
	-	27	DO 28 I1=1,NP	00006550
			I=NC=I1	00006560
			B(I)=H(I)=P*B(I+1)=Q*B(I+2)	00006570
		28	C(I)=B(I)=P*C(I+1)=Q*C(I+2)	00006580
	C-			00006590
	C-		TEST FOR CONVERGENCE OF BATRSTOW PROCESS	00006600
	C-		TEOT TO THE CONTENTE OF DETROIS TO THE COURT	00006610
			IF(H(2)) 30,29,30	00006620
		29	IF(ABS(B(2)/H(1))=E) 31,31,32	00006630
			IF(ABS(B(2)/H(2))=E) 31,31,32	00006640
			IF(ABS(B(1)/H(1))-E) 42,42,32	00006650
			CBAR=C(2)=8(2)	00006660
		36	D=C(3)**2=CBAR*C(4)	00006670
			IF(0) 34,33,34	00006680
		2 2	P=P=2.	00006690
		33	Q=Q+(Q+1.)	00006700
			GO TO 35	00006710
		2.4	P=P+(B(2)*C(3)=B(1)*C(4))/D	00006720
		34	Q=Q+(-B(2)*CBAR+B(1)*C(3))/D	00006730
		26	CONTINUE	
		37	E=E+10.	00006740
,				00006750
		24	IF(E=CONV) 22,22,36	00006760
		30	CONV=E	00006770
			GO TO 42	00006780
	C =		LINEAR COURTE AND CIORE LINEAR CORE	00006790
	C =		LINEAR. COMPUTE AND STORE LINEAR ROOTS	00006800
	C =		NO - NO - 4	00006810
		37	NC=NC-1	00006820
			V(NC)=0.	00006830

```
IF ( IREV ) 34.39,39
                                                                                00006846
      38 U(NC)=1./R
                                                                                00006850
         GO TO 40
                                                                                00006860
      39 U(NC)=R
                                                                                00006870
                                                                                00006880
      40 DO 41 T=1.NC
      41 H(I) = B(I+1)
                                                                                00006890
         GO TO 7
                                                                                00006900
  C -
                                                                                00006916
  0 =
         QUACHATIC. SOLVE QUALRATIC AND STORE ROOTS
                                                                                00006926
                                                                                00006930
  0 =
      42 NC=NC=2
                                                                                00006946
        IF (IREV) 43,44,14
                                                                                00006950
                                                                                00006960
      43 QP=1./Q
         PP=P/(Q*2.0)
                                                                              . 00006976
         GB TO 45
                                                                                00006980
      AA QP=Q
                                                                                00006996
                                                                                00007006
         PP=P/2.0
      45 F=(PP) * + 2=QP
                                                                                0000/010
                                                                                00007020
         IF(F) 46,47,47
C-21
                                                                                00007030
  C =
         CASE OF IMAGINARY RUDIS.
                                                                                00007040
  C-
                                                                                00007050
  C =
      46 U(NC+1)=-PP
                                                                                00007060
         U(NC)==PP
                                                                                00007070
         V(NC+1)=SWRT(-F)
                                                                                00007080
         V(NC) = -V(NC+1)
                                                                                00007090
         GO TO 48
                                                                                00007100
  0-
                                                                                00007110
                                                                                00007120
  C =
         CASE OF REAL ROOTS
                                                                                00007130
  C =
     47 U(NC+1)==SIGN(ARS(PP)+SQRT(F),PP)
                                                                                0000/140
         V(NC+1)=0.
                                                                                00007150
         U(NC)=QP/U(NC+1)
                                                                                00007160
                                                                                00007176
         V(NC)=0.
                                                                                00007186
  C =
         FORM NEW REDUCED COEFFICIENTS
                                                                                00007190
  C =
  C-
                                                                                00007200
                                                                                00007210
      48 DO 49 T=1, NC
```

49 H(I)=B(I+2)
GO TO 7
50 RETURN
END

## APPENDIX D

TIME HISTORY PLOT DIAGRAM CARD LIST



```
SCARD FREFFORM
                                                                            000000000
FILE
      1=TIMEPIT/DATA, HNIT=DISK, SAVE=30, LOCK, ALOCKING=3, KECORD=10
                                                                            00000016
FILE 2=D/H,UNIT=REMUTE, LOCK, RECORD=9
                                                                            00000020
FILE 3=PRIASP, UNIT=PRINTER, KFCDRD=15
                                                                            00000030
FILE 4=FORP/DSK,UNIT=DISK,SAVE=30,10CK,AREA=5000,RECORD=30
                                                                            000000046
FILE 5=APER/DATA, UNIT=DISK, SAVE=30. LUCK, BLUCKING=3, RECURD=10
                                                                            00000056
      REAL NG
                                                                            000000000
      DIMENSION XLARE (2), YLABEL (3), CONTRL(8), TITLE (11)
                                                                            00000076
      DIMENSION NG(14), DG(14), ROOTR(14), ROOTI(14), OUTPUT(1002), I(1002), 00000080
                FORCE(6,2), NC(5), NT(15), 7ERUR(10), 7EROI(10)
                                                                            000000090
      COMMON TOEL . TMAY
                                                                            00000166
      DATA FORCE/MIMPHIM, MSTEFM, MRAMPM, MPULSM, MRAMPM, MSINUM, MLSFM,
                                                                            00000116
                  " "," ","F","STFP","SOID"/
                                                                            00000120
      DATA(XLAPEL(I), T=1,2)/12HTIME-(SEC) /
                                                                            00000130
      DATA(YLAREL(I)) t=1,3)/18HDHTPHT=RFSPONSF /
                                                                            00000140
    ****TIMEPLI/HUMP** SOURCE IS TIMEPLI/SORSE DR. D.F. HUMPHREYS
                                                                            00000150
      ITF=0 ; KK==1
                                                                            00000160
C =
     99 FORMAT(//, "+++++ NOW, RUN: THE PROGRAM PLOT/HUMP+++++")
                                                                            000001/0
 100 FORMAT(8F10.3)
                                                                            00000186
 105 FORMAT (4F20.4)
                                                                            00000196
 106 FORMAT (5F15.3)
                                                                            00000200
      READ(1,4000) (TTTLE(1), I=1,11)
                                                                            00000216
 4000 FORMAT(1146)
                                                                            00000220
      READ(1)/ ) IF , TOFL , TMAX, RTIME, PTIME, W, IPLUT, IWKITE
                                                                            00000550
   1 READ(1,/,END=3) TNGM1,GAIN
                                                                            00000236
      IF (INGM1.GT.O)GO IU 2
                                                                            00000240
      ZEROR(1)=-1, ; GO TO 215
                                                                            00000250
   2 READ(1,/)(7FROR(1), ZEKOI(1), I=1, INGM1)
                                                                            00000260
 215 READ(1,/)1DGM1
                                                                            00000270
      READ(1,/)(R(10TR(1),R(1)),I=1,[0GM1)
                                                                            00000286
      IF (INGM1.GT.1)Gn TO 212
                                                                            00000290
      NG(1) = -7EROR(1)
                                                                            00000300
      NG(2) = INGM1 \times 1.
                                                                            00000310
      ING=TNGM1 + 1
                                                                            000000326
      GO TO 4
                                                                            00000336
  212 CALL CPMPY (7EROP, 7EROL, INGM 1, NG, ING)
                                                                            00000346
   4 CONTINUE
                                                                            00000356
                                                                            00000360
```

```
00000370
C-
                                                                            00000380
C-
                                                                            00000390
      KK=KK+1
                                                                            00000400
      ITF=ITF + 1
                                                                            00000410
  107 FORMAT(1H1)
                                                                            00000420
      AMP=GAIN
                                                                            00000430
C-
                                                                            00000440
         IF - FORCING FUNCTION INDICATOR
C =
                                                                            00000450
                  IF=0 IMPLIES AN IMPULSE
C-
                                                                            00000460
                  TF=1 IMPLIES A STEP
C-
                                                                            00000470
                 IF=2 IMPLIES A RAMP
C-
                                                                            00000480
                 IF=3 IMPLIES A PULSE
C-
                 IF=4 IMPLIES A RAMPSTEP
                                                                            00000490
C -
                                                                            00000500
                  IF=5 IMPLIES A STNIISOID
C=
                  TIME (IF AMP PTIME , RTIME , W, OUTPUT, T, IO, NG, ING, ROOTR)
                                                                            00000510
      CALL
                                                                            00000520
                       ROOTI, IDGM1, ICODE)
                                                                            00000530
      WRITE(3,208)ITF
                                                                            00000540
  208 FORMAT(/,1x, "*****TIME RESPONSE RUN NUMBER",13," ******)
                                                                            00000550
      WRITE(3,98)
   98 FORMAT( / ,10x, "THE COFFFTCIENTS OF THE NUMERATOR"/)
                                                                            00000560
                                                                            00000570
      DO 70 I=1, ING
                                                                            00000580
   70 WRITE(3,101)I,NG(I)
                                                                            00000590
  101 FORMAT(10X, "NG(", I1,") = ", F17.7)
      IF(INGM1.EQ.0)GN TO 216 } WRITE(3,210)
                                                                            00000600
                                                                            00000610
  210 FORMAT (////10x, "THE ZEROS OF THE NUMERATOR"/)
                                                                            00000620
      DO 82 I=1, INGM1
                                                                            00000630
   82 WRITE(3,209)1, ZFROR(1), ZERNI(1)
                                                                            00000640
  209 FORMAT(10x, "ZERn(", I1, ") = ", F17.7," + J ", F17.7)
                                                                            00000650
  216 WRITE(3,102)
  102 FORMAT(////10x, "THE ROOTS OF THE DENOMINATOR"/)
                                                                           000-0560
                                                                            00000670
      DO 80 I=1 IDGM1
                                                                            00000680
   80 WRITE(3,103)I, ROOTR(I), ROOTI(T)
                                                                            00000690
  103 FORMAT(10X, "ROOT(", I1,")=", F17.7," + J ", F17.7)
                                                                           00000700
      WRITE(3,104) IF, (FORCE(IF+1, I), I=1,2), AMP
  104 FORMAT(////1X, "THE FORCING FUNCTION INDICATOR (IF) =", 13,/,
                                                                            00000716
                                                                            00000720
          " THIS IMPLIES THAT A ", 244," INPUT WAS USED. ", /,
                                                                            00000730
                  " AMPLITUDE=" FIT . 7 . //)
                                                                            00000740
      IF(IF.EQ.3) WRITE(3,205) PTIME
```

```
205 FORMAT( /20x . "PTIME=" , F17 . 7)
                                                                            00000750
      IF(IF.EQ.4) WRITE(3,204) RTIME
                                                                            00000760
  204 FORMAT ( /20x, "KTIME WAS ADJUSTED TO ", F10.4," SECUNDS.")
                                                                            000007/4
      IF (IF. FQ. 5) WRITE (3, 206) W
                                                                            00000786
  206 FURMAT(/ 20X, "FREQUENCY=", F17 7)
                                                                            00000796
     IF (ICODE.FR.O) GU TO 302; WRITE(3,96) ICODE
                                                                            000000800
     96 FORMAT(//," ICDDE =", 110)
                                                                            000000816
      IF (ICODE, FQ. 1) WRITE (3,201)
                                                                            00000820
201 FORMATC//10X, "THE COMPLEX PART OF THE OUTPUT VECTOR BECAME",
                                                                            00000836
      "SIGNIFICANT")
                                                                            00000840
      IF(ICODF.EQ.2)WRITE(3,202)
                                                                            00000856
202 FORMAT(//10x, "MULTIPLE ROOTS ENCOUNTERED")
                                                                            00000860
      TECTCODE.EQ.3) WRITE(3.203)
                                                                            00000870
203 FORMAT (//10x + "BAD ENTRY - CHECK POLYNUMIAL DRUERS OF T.F.")
                                                                            000000880
      IF (ICODE NF.O) GO TO 1
                                                                            00000890
     XMAX=T(1)
302
                                                                            00000900
      XMIN=T(1)
                                                                            00000914
      YMAX=OUTPUT(1)
                                                                            00000926
      YMIN=DUTPUT(1)
                                                                            00000930
      FLENUM=TMAX/TDFL
                                                                            00000940
      IIH=FLENUM + 1.0
                                                                            00000956
      DO 600 KI=1. IIH
                                                                            00000966
      IF(T(KI).LT, XMIN)XMIN=T(KT)
                                                                            00000910
      IF (T(KI).GT.XMAY)XMAX=T(KI)
                                                                            U8600000
      IF (CHIPUT(KI), GT, YMAX) YMAX=DUTPUI(KI)
                                                                            00000990
      IF(OUTPUT(KI).LT.YMIN)YMIN=GUTPUT(KI)
                                                                            00001000
 600 CUNTINUE
                                                                            00001010
      WRITE(3,97)
                                                                            00001020
  97 FORMAT(1H1,///,8X,"TIME",13X,"OUTPUT",/)
                                                                            00001030
      DO 10 I=1, IO, 2
                                                                            00001040
  10 WRITE(3,200)T(1), OUTPUT(1)
                                                                            00001050
 200 FORMAT(2F17.7)
                                                                            00001060
      WRITE(3,107)
                                                                            00001070
     IF (IWRITE . FQ . n) GO TO 11
                                                                            00001080
      ITER=1
                                                                            00001096
      WRITE(5,213)
                                                                            00001100
     WRITE(5,214) ITER, TMAX, IDGMI, ITH
                                                                            00001110
 213 FORMAT(30X)
                                                                            00001120
```

```
00001130
 214 FORMAT(15, F10.1.215)
                                                                        00001140
C =
                                                                        00001150
  12 WRITE(5,207)(OUTPUT(I), I=1, IO)
                                                                        00001160
 207 FORMAT(5(E12.5,1X))
                                                                        00001170
  11 CONTINUE
                                                                        00001180
      IF(IPLOT.EQ.O)Gn TO 1
                                                                        00001190
      DX=(XMAX=XMIN)/7. 3 DY=(YMAX=YMIN)/5.
                                                                        00001200
      IF(ABS(DY).GT..00001)GOT0334 ; WRITE(3,301) ; GOT01
                                                                        00001210
  334 IF(KK.GT.0)GO TO 700
                                                                        00001220
     CALL PLOT(0,-12,-3) ; CALL PLOT(1,1,-3) ; GO TO 800
                                                                        00001230
 700 CALL PLOT(12,0,-3)
                                                                        00001240
 800 CONTINUE
 301 FORMAT(///," *****NO PLOT FOR LAST QUTPUT***** ")
                                                                        00001250
      A=Q. ; IF(YMIN.IT.O..AND.YMIN+DY×5.GT.O.)A=-YMIN/DY
                                                                       00001260
                                                                       00001270
      CALL AXIS(0, A, XI ABEL, -11,7,0, XMIN, DX)
                                                                        00001280
     CALL AXIS(0,0,YI AREL, 15,5,90,YMIN,DY)
                                                                        00001790
     CALL LINE(T, OUTPUT, IIH, 1, 0, 3, XMIN, DX, YMIN, DY)
                                                                       00001300
      GO TO 1
                                                                        00001310
   3 CONTINUE 3 IF(IPLOT.EQ.0)GO TO 217
                                                                        00001320
      CALL PLOT (0,0,999)
                                                                        00001330
         LOCK 4
         WRITE(2,107) JC= WRITE(2,99)
                                                                        00001340
                                                                        00001350
 217 STOP
                                                                        00001360
      END
                                                                        00001370
      SUBROUTINE CPVAL (RES, ARG, X, TDTMX)
                                                                        00041380
        COMPLEX RESPARG
                                                                        0006 390
     DIMENSION X(20)
                                                                        000011400
     RES=(0.,0.)
                                                                        0000 410
     J=IDIMX
                                                                        00001420
   1 IF(J)3,3,2
                                                                        00001430
   2 RES=RES*ARG+X(J)
                                                                        00001440
     J=J-1
                                                                        00001450
     GO TO 1
                                                                        00001460
   3 RETURN
                  00001470
      END
                                                                        00001496
C=
    PURPOSE"
                                                                        00001500
C-
```

D-6

```
D-7
```

```
C -
                                                                           00001510
C =
         THE PURPOSE OF THIS SUBBOUTINE IS TO DETERMINE THE ITME
                                                                           00001526
         RESPONSE OF AN INPUT TO A TRANSFER FUNCTION BY TAKING THE
0 =
                                                                           00001536
         INVERSE LAPLACE TRANSFORM BY THE METHOD OF RESIDUES.
                                                                           00001546
C =
         INTRODUCTION TO AUTOMATIC CONTROL SYSTEMS - ROBERT N. CLARK
C -
                                                                           00001550
         (PP 70 - 77)
                                                                           00001566
( -
C -
                                                                           00001576
C =
                                                                           00001580
     VARIABLES"
                                                                           00001590
C =
C =
         AMP - AMPLITUDE OF THE FURNING FUNCTION
                                                                           00001600
C =
         PTIME = PILLSE TIME (SPECIFIED FOR IF=3)
                                                                           00001616
C =
         RTIME - RAMP TIME (SPECIFIED FOR IF=4)
                                                                           00001620
( m
         W - FREQUENCY OF THE SINUSPIDAL INPUT (SPECIFIED FOR IF=5)
                                                                           00001630
         OUTPUT - VECTOR OF CALCULATED RESPONCE AMPLITUDE VALUES
C -
                                                                           00001640
         T - VECTOR OF SEQUENTIAL TIME VALUES DIRECTLY RELATED TO CUTPUTO0001650
C =
         In - NUMBER OF DUTPUT VALUES (CALCULATED)
C -
                                                                           00001660
         NG - VECTOR OF NUMERATOR CHEFFICIENTS
C-
                                                                           000016/6
         ING - DIMENSION OF THE NUMERATOR COFFFICIENTS
                                                                           00001680
0 -
         ROOTR - VECTOT OF HEAL PARTS OF THE ROUTS
                                                                           00001696
C =
         ROOTI - VECTOR OF IMAGINARY PARTS OF THE ROOTS
                                                                           00001706
C -
         IDGM1 - NUMBER OF KNOTS (ORDER OF THE DENOMINATOR)
                                                                           00001710
C =
                                                                           00001726
C =
         ICODE - RETURN CUDE VARIABLE
C -
                 1000F=0 IMPLIES NORMAL FXECUTION
                                                                           00001730
C -
                 TOODF=1 IMPLIES THAT THE COMPLEX PART OF THE OUIPUL
                                                                           00001740
                          VECTOR RECAME STGNIFICANT.
C -
                                                                           00001750
C-
                                                                           00001760
                                                                           000017/6
C =
                 TCODE=3 IMPLIES THAT THE URDER OF THE DENOMINATUR WAS
                                                                           00001780
C =
                          NOT GREATER THAN THE ORDER OF THE NUMERATOR.
                                                                           00001790
C =
                  ICODF = 4 IMPLIES THAT THE FURCING FUNCTION INDICATOR
C -
                                                                           00001800
                          WAS SPECIFIED INCORRECTLY
                                                                           00001810
C =
C =
                                                                           00001820
C-
                                                                           00001830
     SUBROUTINES CALLED"
                                                                           00001840
C -
                                                                           00001850
C =
C =
         CPVAL - COMPLEX EVALUATION OF A POLYNOMIAL
                                                                           00001860
         TYME - RESPONSE BY THE METHOD OF RESIDUES
C =
                                                                           000018/0
C =
                                                                           00001880
```

```
00001890
C-
                                                                             00001900
     REMARKS"
C -
                                                                             00001910
C =
         THIS SUBROUTINE IS DESIGNED TO GENERATE THE TIME RESPONSE OF A 00001920
C-
                                                                             00001930
         GENERAL DUTPHT FUNCTION XO(S) = X1(S)G(S). IN THIS
C-
                                                                             00001940
         EVALUATION TWO IMPORTANT ASSUMPTIONS ARE MADE.
C-
                  1) THE ORDER OF THE DENOMINATOR OF THE OUTPUT FUNCTIONOCOC1950
C-
                                                                             00001960
                      OF THE OUTPUT FUNCTION.
C -
                                                                             00001970
                      MUST BE LARGER THAN THE ORDER OF THE NUMERATOR
C-
                  2) MULTIPLE ROOTS OF THE DENOMINATOR MAY NOT EXIST.
                                                                             00001980
C-
                                                                             00001990
C=
                                                                            *00002000
                                                                             00002010
C
                                                                             00002020
      SUBROUTINE TIME (IF, AMP, PTIME, RTIME, W, QUTPUT, T, IO, NG, ING, ROOTR,
                                                                             00002030
                       ROOTI, IDGM1, ICODE)
                                                                             00002040
         REAL NG
      DIMENSION P(14), NG(14), K(14), NUT(1002), T(1002), OUTPUT(1002),
                                                                             00002050
                 ROOTR(14), ROOTI(14), SAVE(1002)
                                                                             00002060
                                                                             00002070
      COMMON TDEL, THAY
                                                                             00002080
      ICODE=4
                                                                             00002090
      IF (IF. GT. 5. DR. IF. LT. 0) RETURN
                                                                             00002100
      GAINDG=1./AMP
                                                                             00002110
C-
                                                                             00002120
         DETERMINE TMAX
C=
                                                                             00002130
C-
                                                                             00002140
        SMALL=1.E6
C=
                                                                             00002150
C-
        DD 9 I=1 IDGM1
                                                                             00002160
        ABSR=ABS(ROOTR(I))
C-
                                                                             000021/0
C-
        IF (ABSR.E9.0.) GO TO 10
                                                                             00002180
        IF (ABSR.LT.SMALL) SMALL=ABSR
.C =
                                                                             00002190
C=
                                                                             000002200
      IF(IF.EQ.0)GD TO 11
                                                                             00002210
      GO TO (10,20,30,40,50) , IF
   11 CALL TYME (OUTPUT, T, IO, NG, TNG, ROOTR, ROOTI, IDGM1, GAINDG, ICODE)
                                                                             00005550
                                                                             00002230
      RETURN
                                                                             00002240
   10 IDGM1=IDGM1+1
                                                                             00002256
      ROOTR([DGM1)=n.
                                                                             00002266
      RODTI(IDGM1)=0.
```

```
CALL TYME ( OUTPUT . T . IC , NG . I NG . ROUTR , ROUTI . IUGM1 . GAINDG , I CODE )
                                                                             00002216
   RETURN
                                                                             00062206
20 IDGM1=IDGM1+1
                                                                             00002296
   RUDTR(IDGM1)=.001
                                                                             00002306
   RUNTI(IDGM1)=0.
                                                                             00002310
   IDGM1 = IDGM1 + 1
                                                                             00002320
   RUUTR(IDGM1)==.001
                                                                             00002336
   RODII(IDGM1)=0.
                                                                             00002346
   CALL TYME (MUTPUT, T, IM, NG, ING, ROOTE, ROOTE, INGMI, GAINDG, ICODE)
                                                                             00002350
   RETURN
                                                                             00002366
30 IDGM1=IDGM1+1
                                                                             000023/6
   ROOTR(INGM1)=0.0
                                                                             00002386
   RUDII(IDGM1)=0.0
                                                                             00002390
   CALL TYME (SAVE * T . ID . NG . ING . ROOTH . ROOTI . TOGM 1 . GAINDG . TCODE )
                                                                             00002406
   IF(ICODE . NF . O) GO TU 34
                                                                             00002410
   MTIME=PTIME/TOEL +0.5
                                                                             00002426
   IF (MTIMF. EQ. 0) GO TO 32
                                                                             00002430
   DO 31 I=1,MTIME
                                                                             00002440
31 OUTPUT (I) = SAVE (I)
                                                                             00002456
32 TP1=MTIME+1
                                                                             00002460
   DO 33 I=IP1, IO
                                                                             00002416
33 OUTPUT(T) = SAVE(T) = SAVE(I = MTIME)
                                                                             00002466
34 RETURN
                                                                             00002490
40 I=RTIME/TDEL+.5
                                                                             00002500
   RTIME=I*TDEL
                                                                             00002516
   IDGM1=IDGM1+1
                                                                             00002520
   RUNTR(IDGM1)=.001
                                                                             00002530
   ROOTI(IDGM1)=0.0
                                                                            00002540
   IDGM1=IDGM1+1
                                                                            00002556
   ROOTR(IDGM1)==.001
                                                                            00002560
   ROOTI(IDGM1)=0.0
                                                                            00002570
   GAINDG=GAINDG*RTIME
                                                                            00002586
   CALL TYME (SAVE, T. 10, NG, ING, ROOTR, ROOTI, IDGM1, GAINDG, TOUNE)
                                                                            00002590
   IF(ICODE.NE.O) GO TO 44
                                                                            000012600
   MTTMF=RTIMF/The1+0.5
                                                                            00002610
   IF (MTIMF.EQ.O) GO TO 42
                                                                            00002620
   DU 41 I=1 MTIME
                                                                            00002630
41 OUTPUT(1)=SAVE(1)
```

00002646

```
00002650
42 IP1=MTIME+1
                                                                         00002660
   DO 43 I=IP1,10
                                                                         00002670
43 OUTPUT(1)=SAVE(1)=SAVE(1=MTTMF)
                                                                         00002680
44 RETURN
                                                                         00002690
50 IDGM1=IDGM1+1
                                                                         00002700
   ROOTR(IDGM1)=0.
                                                                         00002710
   ROOTI(IDGM1)=W
                                                                         00002720
   IDGM1=IDGM1+1
                                                                         00002730
   RODTR(IDGM1)=0.
                                                                         00002740
   ROOTICIDGM1)=-W
   CALL TYME (OUTPUT, T, 10, NG, TNG, ROOTR, ROOTI, IDGM1, GAINDG, ICODE)
                                                                         00002750
                                                                         00002760
   RETURN
                                                                         00002770
   DEBUG SUBCHK
                                                                         00002780
   SUBROUTINE TYME (OUTPUT, TO, NG, ING, ROOTR, ROOTI, TDGM1, GATNOG, ICODE) 00002790
     COMPLEX P.S. OUT, OUT1, K, KJ, KNUM
                                                                          00002810
   DIMENSION P(14), NG(14), K(14), NUT(1002), OUTPUT(1002), T(1002),
     REAL NG
                                                                          00002820
                                                                          00002830
              ROOTR(14), ROOTI(14), TTEST(16)
                                                                          00002840
   COMMON TOEL, THAX
                                                                          00002850
                                                                          00002860
      CHECK FOR BAD ENTRY
                                                                          00002870
                                                                          00002880
   IF(IDGM1.LT.ING) GO TO 55
                                                                          00002890
                                                                          00002900
       CHECK FOR MULTIPLE ROOTS
                                                                          00002910
                                                                          00002920
   DO 5 I=1, IDGM1
                                                                          00002930
    RRP1=ROOTR(I)+.0001
                                                                          00002940
    RRM1=ROOTR(I)-.0001
                                                                          00002950
    RIP1=ROOTI(I)+.0001
                                                                          00002960
    RIM1=ROOTI(I)=.0001
                                                                          00002970
    00 5 J=1 . IDGM1
                                                                          00002980
    IF(I.EQ.J) GO TO 5
                                                                          00002990
    RRJ=ROOTR(J)
                                                                          00003000
    IF(RRM1.LT.RRJ.AND.RRP1.GT.RR.J.AND.RIM1.LT.RTJ.AND.RIP1.GT.RIJ)
    RIJ=ROOTI(J)
                                                                          00003010
                                                                           00003020
```

C=

7 -

C-

C-

C-

C-

C-

C-

GO TO 50

00063036

00003400

GO TO 5

T(IC)=T1

```
D-12
```

```
IF(T1.LT.TMAX) GO TO 34
                                                                            00003410
      IF(ABS(UNREAL).GT..O1)WRITE(3.102)
                                                                            00003420
  102 FORMAT(1H1)
                                                                            00003430
      RETURN
                                                                            00003440
      ICODE=3
 55
                                                                            00003450
      RETURN
                                                                            00003460
C-
      DEBUG SUBCHK
                                                                            00003470
      END
                                                                            00003480
      SUBROUTINE PLOTEX, Y, IPEN)
                                                                            00003490
      DIMENSION CONT(9)
                                                                            00003500
      DATA CONT/51HCCFX PLOT/HUMP+577351002 FILE FILERAY=FORP/DSKJEND./ 00003510
C=
                                                                            00003520
      BCD = C6H
                    P)
                                                                            00003530
      WRITE(4)BCD, X, Y, IPENJIF(IPFN.NE. 999)RETURNJLOCK 4
                                                                            00003540
      CALL ZIP(CONT) JRETURN
                                                                            00003550
      END
                                                                           00003560
      SUBROUTINE SYMBOL (X, Y, SZ, BCD, ANG, NC)
                                                                            00003570
      DIMENSION BCD(13)
                                                                           00003580
      T=(6H
                S)
                                                                           00003590
                   NW1=6
                                                                           00003600
      IF(MOD(NC,6).EQ.O)NW1=0
                                                                           00003610
      NW = (IABS(NC)+ NW1)/6
                                                                           00003620
      WRITE(4) T, X, Y, SZ, ANG, NC, (BCD(T), I=1, NW)
                                                                           00003630
      RETURN
                                                                           00003640
     END
                                                                           00003650
      SUBROUTINE AXIS(X, Y, BCD, NC, AXI EN, ANG, RMIN, DEL TV)
                                                                           00003660
     DIMENSION ACD(13)
                                                                           00003670
     T = (6H
                 A)
                                                                           00003680
                    NW1=6
                                                                           00003690
     IF(MOD(NC,6).EQ.0)NW1=0
                                                                           00003700
     NW = (IABS(NC) + NW1)/6
                                                                           00003710
     WRITE(4)T, X, Y, NC, AXLEN, ANG, RMIN, DELTV, (BCD(I), I=1, NW)
                                                                           00003720
     RETURN
                                                                           00003730
     END
                                                                           00003740
     SUBROUTINE LINE(PX, PY, NPT, INC. LTYP, ISM, FIRSTX, DELTX, FIRSTY, DELTY) 00003750
     DIMENSION PX(NPT), PY(NPT), RCD(1)
                                                                           00003760
     INTEGER ASTEMPS R.C.
                                                                           00003770
     S = (6H
                                                                           00003780
```

```
P = (6H
                 P)
                                                                               00003790
       S/ = . 08
                                                                               00003800
      ANG =0.0 ; IX =1
                                                                               00003816
   20 A=1
                                                                               00003820
      R = TABS(TNC)
                                                                               00003830
       C=NPT
                                                                               00003840
      NA = 0
                                                                               00003856
       IC = 3
                                                                               00003860
      IS ==1
                                                                               00003870
       ICA = 2
                                                                               00003880
      ISA == 2
                                                                               00003890
      NT = 1
                                                                               00003900
      IF (LTYP) 30, 40,50
                                                                               00003916
   30 \text{ ISA} = -1
                                                                               00003926
      B = R *LTYP + ISA
                                                                               00003930
      GO TO 60
                                                                               00003946
   40 NT = -1
                                                                               00003950
      GO TO 60
                                                                               00003960
   50 NT =LTYP; NA==1+NT
                                                                               00003970
   60 IF(ISM=3)80D(1)=(6H+00000)
                                                                               00003980
      IF(ISM=1)8CD(1)=(6H000000)
                                                                               00003996
      DD 100 I=A,C,H
                                                                               00004000
      XPT = (PX(I) - FIRSTX)/DELTX
                                                                               00004010
      YPT = (PY(I) =FIRSTY)/DELTY
                                                                               00004020
      NA =NA+1
                                                                               00004030
      IF (NA=NT)GO TO 110
                                                                               00004040
      WRITE(4)P, XPT, YPT, IC
                                                                               00004056
      GO TO 105
                                                                               00004060
  110 WRITE(4)S, XPI, YPI, SZ, ANG, TY, HCD(1)
                                                                               00004076
      NA = 0
                                                                               00004086
  105 IC = ICA
                                                                               00004090
      IS = ISA
                                                                               00004100
  100 CONTINUE
                                                                               00004116
      RETURN
                                                                               00004126
      FND
                                                                               00004130
                                                                               00004140
SURROUTINE CPMPY(ZERUR, /EROI, INGMI, A, IDIMZ)
                                                                               00004150
COMPLEX X,Y,Z
                                                                               00004160
```

```
00004170
DIMENSION X(28), Y(28), Z(28), ZEROR(28), ZEROI(28), A(28)
                                                                            00004180
DO 11 I=1, INGM1
                                                                            00004190
      ZEROR(I)=-ZEROR(I)
11
                                                                            00004200
      X(1)=CMPLX(ZEROR(1),ZEROI(1))
                                                                            00004210
      X(2)=(1.,0.)
                                                                            00004220
      IDIMX=2
                                                                            00004230
      Y(2)=(1.,0.)
                                                                            00004240
      IDIMY=2
                                                                            00004250
      MAXDO=INGM1 - 1
                                                                            00004260
DO 1 TO=1, MAXDO
                                                                            00004270
      J=10 + 1
                                                                            00004280
      Y(1)=CMPLX(ZEROR(J), ZEROI(J))
                                                                            00004290
      IDIMZ=IDIMX + IDIMY - 1
                                                                            00004300
  DO 30 I1=1, IDIMZ
                                                                            00004310
    Z(I1)=(0.,0.)
                                                                            00004320
  DO 40 12=1, IDIMX
                                                                            00004330
  DO 40 J1=1, IDIMZ
                                                                            00004340
      K=12 + J1 - 1
                                                                            00004350
  40 Z(K)=X(12)\times Y(J1) + Z(K)
                                                                            00004360
  DO 50 13=1 , IDIMZ
                                                                            00004370
  50 \times (13) = Z(13)
                                                                            00004380
      IDIMX=IDIMZ
                                                                            00004390
DO 60 TA=1, IDIMZ
                                                                            00004400
      A(IA)=REAL(Z(IA))
60
                                                                            00004410
DO 20 J=1, INGM1
                                                                            00004420
      ZEROR(J)==ZEROR(J)
20
                                                                            00004430
      RETURN
                                                                            00004440
```

END

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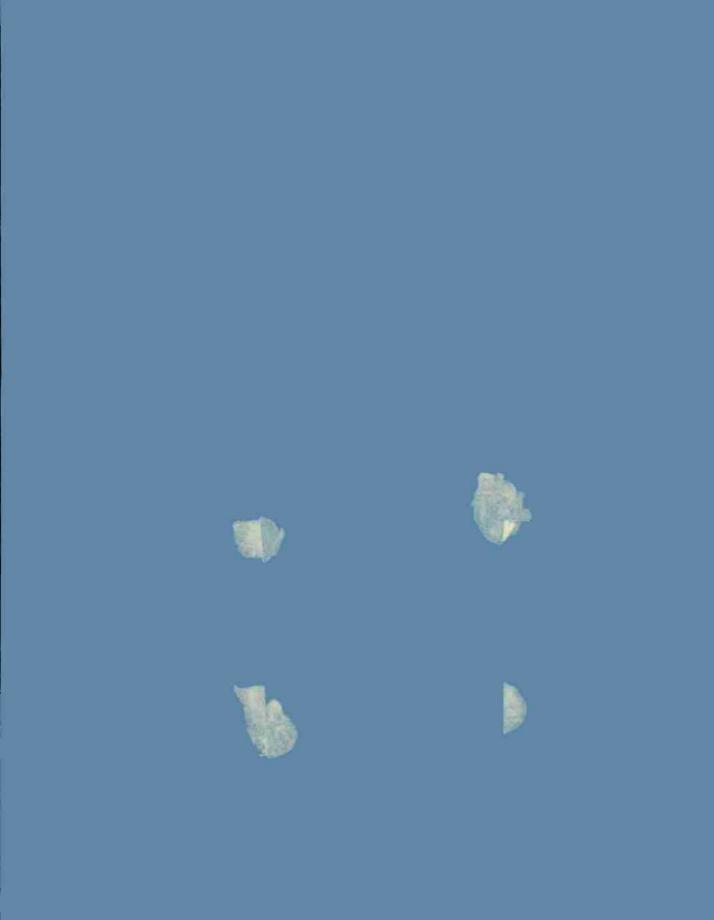
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